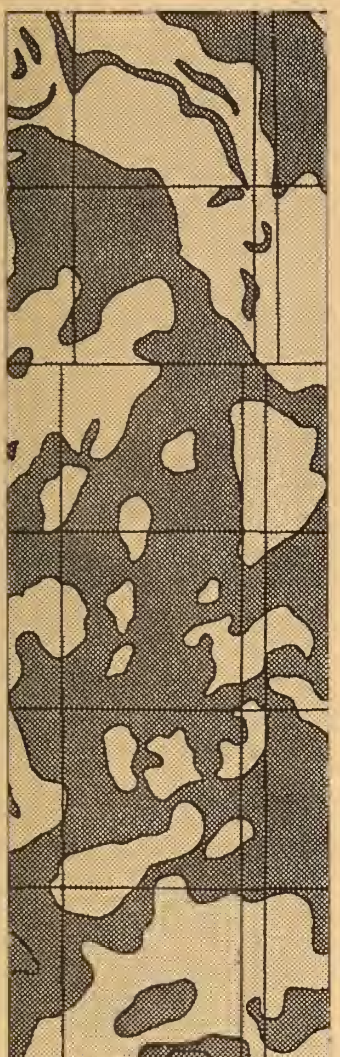
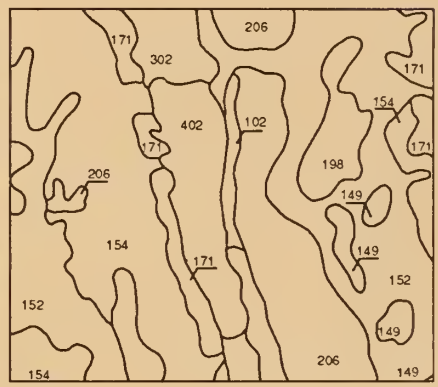
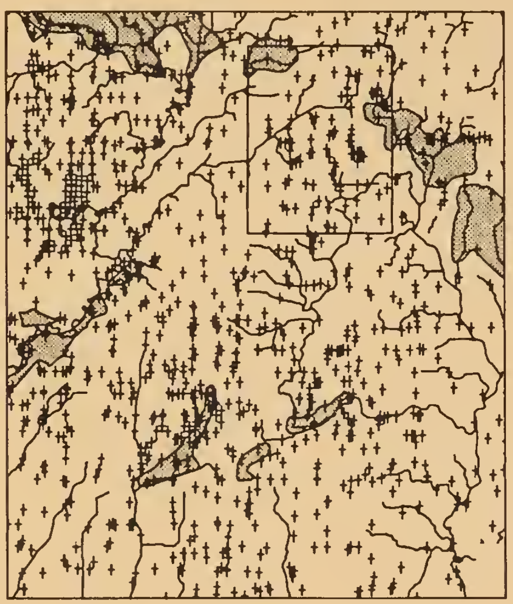
ILLINOIS GEOGRAPHIC INFORMATION SYSTEM
Applications to Environmental Management



Robert J. Krumm and Anne L. Erdmann
Illinois State Geological Survey

Mark G. Joselyn
Illinois Natural History Survey





1991

ENVIRONMENTAL
GEOLOGY 140

Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY

ILLINOIS GEOGRAPHIC INFORMATION SYSTEM
Applications to Environmental Management

Robert J. Krumm and Anne L. Erdmann
Illinois State Geological Survey

Mark G. Joselyn
Illinois Natural History Survey

1991

ENVIRONMENTAL
GEOLOGY 140

ILLINOIS STATE GEOLOGICAL SURVEY
Morris W. Leighton, Chief

Natural Resources Building
615 East Peabody Drive
Champaign, Illinois 61820

CONTENTS

Note: The use of specific hardware and software product names is for informational purposes only and does not constitute an endorsement by either the Illinois State Geological Survey or the Illinois Department of Energy and Natural Resources.

Printed by the authority of the State of Illinois 1991/1000.

ABSTRACT

In 1983, the Illinois Geographic Information System (IGIS) was started as a cooperative effort of five divisions of the Illinois Department of Energy and Natural Resources (ENR): the Illinois State Geological, Water, and Natural History Surveys; the Illinois State Museum; and the Office of Research and Planning. The IGIS has since become an integral part of ENR and is used daily by geologists, biologists, hydrologists, engineers, archaeologists, planners, and other professionals for such diverse projects as mapping mineral resources, identifying habitats of endangered species, and assessing sites for the disposal of hazardous waste.

The power and flexibility of a Geographic Information System (GIS) come primarily from two characteristics: it operates with geographically referenced data and it is computer based. The IGIS currently consists of a network of hardware located in Champaign and Springfield, Illinois. GIS software and many databases are shared among all agencies, who also use specialized hardware and software and maintain project-specific databases (e.g., the Illinois State Geological Survey uses software designed for subsurface geologic investigations).

As the name GIS implies, the geographic or spatial nature of information is fundamental. Geographic location of natural and cultural features provides a framework in which diverse data sets can be compiled and integrated to discover relationships and generate new information. The IGIS database consists of information input from published maps, well logs, and other sources. This digital map database includes base map information, such as county boundaries, and information on mineral resources, wetlands, streams and rivers, hazardous waste sites, and census data. Unlike other computer-based data management systems, GIS allows the user to perform complex analyses on spatial and tabular data. Because maps are the primary source of information for a GIS and maps are frequently used to display the data, GIS is often referred to as computer mapping. But the strength and utility of GIS lie as much in its data management capabilities as in its cartographic output.

This report provides information on the IGIS to agencies and other groups who are just beginning to explore the merits of GIS and to new users who want to be aware of what the Illinois system is and how it is being used. General GIS concepts are introduced. Detailed information is given on the hardware, software, and data that are part of the system and how people participate in it. Basic descriptions are given on how the system works, as well as steps involved in applying GIS technology.

Three examples of GIS applications demonstrate the technical power and utility of the system. At the statewide level, several factors were used to compile a map showing seismic risk zones. At the county level, GIS techniques were used to support a landfill siting study in Champaign County. At the local level, GIS was used to locate the optimal site in Kane County as part of the Illinois bid for the Superconducting Super Collider, a high-energy physics facility. Each study required a unique approach using data at different scales.

ACKNOWLEDGMENTS

Preparation of this document was supported in part by funding from Illinois General Assembly through grant ENR-5SSC. The authors gratefully acknowledge this support, as well as the continued support of the IGIS program by the Illinois Department of Mines and Minerals. The authors thank Colin G. Treworgy, Donald A. Keefer, and E. Donald McKay for their review of this manuscript.

INTRODUCTION

A growing number of public and private organizations are turning to a Geographic Information System (GIS) as a means to deal with many aspects of environmental issues, including research, policy making, enforcement, and management. This report discusses the components and functions of GIS in general and describes in more detail the Illinois Geographic Information System (IGIS). This report should be particularly useful to those agencies and groups who are just beginning to explore the merits of GIS and who may be interested in the Illinois system.

The IGIS was developed in 1983 within the Illinois Department of Energy and Natural Resources (ENR) under initial sponsorship of the Illinois Department of Mines and Minerals. The system was originally designed to create and maintain extensive files of natural resource, cultural, and socioeconomic data needed to provide efficient, accurate analyses of petitions under the Lands Unsuitable for Mining Program. While this function continues, the uses of the system have been greatly expanded to include a multitude of research and service tasks for ENR, Illinois Department of Mines and Minerals, and other state agencies. In particular, the development and use of GIS in the proposal to site the Superconducting Super Collider (SSC) for Illinois greatly increased GIS capabilities at ENR. The increased value of GIS as a research tool resulting from data and expertise acquired during the SSC project prompted this report.

As the name GIS implies, the geographic nature of information is fundamental. Geographic location is the common element allowing diverse sets of information to be brought together. The IGIS database consists of information input from a variety of published maps, well logs, and other sources. This digital map database includes base map information, such as county boundaries and township lines, as well as information on mineral resources, wetlands, streams and rivers, hazardous waste sites, census data, and many other features. Although the IGIS is used mainly by ENR staff, other state agencies, groups, and individuals also use the system to support other projects in Illinois. The Illinois Department of Mines and Minerals and Department of Conservation are currently using the IGIS for several research and service projects.

The IGIS, one of the largest state-level GIS installations in the United States, has proven its value through many research and planning projects. Geologists, planners, biologists, engineers, hydrologists, archaeologists, and other professionals are using this system to conduct new research aimed at understanding and preserving the past while addressing Illinois' future growth and development. As scientists and decision makers develop plans for the state, they will confront many environmental, social, and economic issues. The IGIS can be an invaluable tool for integrating and synthesizing the information needed to make critical choices and solve problems that face Illinois.

GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

The power and flexibility of GIS comes primarily from two characteristics: it operates with geographically referenced data and it is a computer-based system. GIS has been defined as a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information (Dueker and Kjerne 1989).

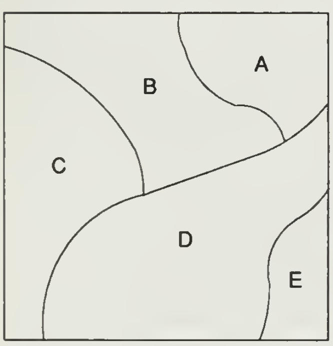
Geographic location of natural and cultural features provides a unifying framework so that diverse data sets can be compiled and integrated to discover relationships and generate new information. Like other computer-based data management systems, GIS allows the user to perform complex analyses. Because maps are the primary source of information for a GIS and maps are frequently used to display the data, GIS is often referred to as computer mapping. But the strength and utility of GIS lie as much in its data management capabilities as in its cartographic output.

Managing Map Data in a GIS

Information on any map is presented graphically with lines, colors, map symbols, and text. GIS map layers, often called coverages, are more than graphic drawings stored in a computer. They are digital files with two key components: the location and attributes associated with the location. Representing this information in a GIS requires the use of specific data structures. Three common data structures are vector, raster, and tabular (fig. 1).

Raster and vector data structures are used to capture and manipulate graphic map features. In a raster-based system, information is represented by a grid of rectangular cells, called grid cells (fig. 1). This data structure is very efficient for processing and display. Data collected by remote sensing techniques, such as satellite imagery, are commonly captured, processed, and used in a raster format. One limitation of the raster structure is that feature resolution is controlled by the size of individual cells. As a result, the exact feature position (e.g., a boundary between two soil types) can be anywhere within the grid cell. In addition, linear features, such as rivers, must be represented by grid cells. Early raster systems required that all cells be the same size. Consequently, GIS users were faced with making tradeoffs between small grid sizes (which accurately represented features but increased data storage requirements) and large cells (which took less storage space but exaggerated or omitted features and produced blocky map output). Recently, raster-based systems, developed for the GIS, allow multiple cell sizes and the incorporation of linear or point features.

VECTOR



RASTER

B	B	B	B	B	B	A	A	A	A
C	B	B	B	B	B	B	A	A	A
C	C	B	B	B	B	B	A	A	A
C	C	C	B	B	B	B	B	A	A
C	C	C	C	B	B	B	D	D	D
C	C	C	C	D	D	D	D	D	D
C	C	C	D	D	D	D	D	D	D
C	C	D	D	D	D	D	D	E	E
C	C	D	D	D	D	D	D	E	E
C	C	D	D	D	D	D	D	E	E

TABULAR

Census Data

Land-use Information

Soils Data

Soil	Class	Suitability
A3	113	high
C6	95	low
B7	212	moderate
B13	201	moderate
Z22	86	low
A6	77	high
A1	117	low

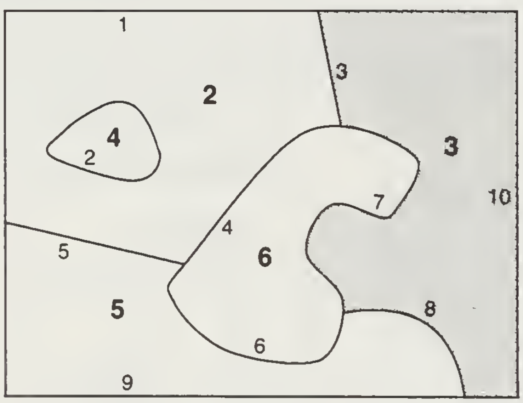
Figure 1 Three common GIS data formats. In a GIS, tabular data are linked to either vector or raster map information.

In a vector data structure, map features are represented by points, lines, and polygons, depending on the type of feature and scale of the source map. Point data are stored as pairs of *x-y* coordinates and represent single feature locations, such as a water well, stream gauging station, or benchmark. Lines, stored as a series of points, represent linear features, such as streams, faults, or pipelines. Polygons are used to represent areal features and are stored as lines that enclose an area. A lake or reservoir, a regional aquifer, or a particular soil unit are examples of data represented by polygons. A vector GIS is generally slower and lacks some of the analytical capabilities of a raster GIS, but produces more cartographically pleasing output and provides more accurate representation of the shape and position of mapped features. Many GIS packages are either raster or vector based, but some systems utilize both structures. Organizations that must have accurate boundary locations, such as land parcels, or must deal with linear features, such as utility lines, tend to prefer vector systems. Organizations that are more interested in modeling natural phenomena, such as air quality, soil erosion, or geologic units, may prefer raster systems.

Tabular information is handled by a GIS through relational database management systems, such as INFO, dBase, or Oracle. Each map-feature attribute is stored by the GIS in a table format. Examples of attribute data include sample location numbers, street addresses, strength measurements for a particular rock type, or water-depth measurements (fig. 2). Although a tabular database can be used independently of the graphic map information, GIS capabilities integrate attribute data with graphic map features to allow mapping and spatial analysis. An internal tabular database is one of the essential elements of a GIS. Vector and raster systems generally contain links to tabular data.

GIS Compared wlth CAD/CAM

Many similarities are apparent between GIS and Computer-Aided Drafting (CAD) Computer-Aided Mapping (CAM) software. GIS and CAD/CAM software are designed to manage and manipulate graphic map information, and the maps produced using any of these systems may look very similar. However, analytic capabilities are provided by most GIS packages that are not provided by most CAD/CAM software. The analytic functions of GIS are tied to the topological data structure that is common to most GIS software but generally lacking from CAD/CAM.



Polygon	Rock type	Line no.
2	shale	1,3,4,5,2
3	limestone	3,7,8,10
4	coal	2
5	...	
6	...	

Line	Class	Adjacent Polygons
1	map boundary	1,2
2	unit boundary	2,4
3	fault	2,3
4	unit boundary	2,6
5	...	...
6	...	...

Figure 2 Example showing how topology establishes relationships between polygon and line features. Polygons, representing geologic units, are identified with bold numbers. Lines, representing various boundaries, are indicated with smaller numbers. This information on adjacency is determined and stored by the GIS software.

In a cartographic context, topology is defined as the mathematical description of geographic features and their relationships relative to one another (White 1980, ESRI 1987). Information about map relationships, such as area definition, connectivity, and adjacency, is derived from stored topological relationships. For example, a line feature, such as a fault, may also represent a contact between two geologic units, which are polygon features (fig. 2). This information (what geologic units are bounded by a common fault) is carried by a topologically structured GIS. CAD/CAM systems generally lack topological data structures and therefore cannot recognize these types of spatial relationships.

Data layers in CAD/CAM systems may be displayed individually or in combination, but since CAD/CAM systems lack topological data structures, they cannot determine distances and adjacency of map features. For example, two map layers, such as soils and land use, can be plotted over one another in a CAD/CAM system, but the software lacks the capability to integrate the information and determine specific areas (in acres or square feet) for many of the possible combinations of soil type and land use. Although CAD/CAM systems do allow for map information overlay, the overlay capability is graphic only and does not result in a merging of attribute data from multiple map layers.

Lines and other map features can be represented as layers in a CAD/CAM system, but the graphic data generally are not related to descriptive attribute tables stored in a database management system. Because they lack this sophisticated interface to a database management system, CAD/CAM systems cannot manipulate features on the basis of their attributes, e.g., classify all areas with soil *x*, slope *y*, and vegetation *z* as susceptible to landslides.

GIS Usefulness

GIS is not a panacea for computer mapping or data management. Computer applications involving detailed engineering design plans generally are more suited to a CAD system. What GIS has to offer over other mapping systems is specialized functions for data access, integration, and analysis. These basic GIS functions can complement the decision-making process within an agency or organization. Data availability and access are equally important. Integration and analysis functions of a GIS provide a mechanism for combining information, testing multiple scenarios, and presenting the results in a form that is easy to understand.

Information is a key to understanding and solving any problem. When GIS data sets are well documented, a user can identify and access coverages containing information relevant to a particular problem. Because GIS is capable of integrating diverse sets of data, it is an excellent tool for synthesizing information related to many interdisciplinary problems. GIS can minimize problems (e.g., various scales, map projections, data sources) that may arise when different agencies use a variety of information. However, users should exercise caution before using digital information as a matter of convenience simply because it is already available in digital form. A user should know how and when the original data were collected, as well as the limitations of those data. For example, were the data collected at a suitable scale? A user should carefully consider whether the available data are valid for the intended use; new data may have to be collected to properly deal with the question at hand. The age of the digital files may also be a concern if the analysis requires very recent information.

GIS provides a mechanism for *integration* of data from a variety of sources. Traditional barriers to information sharing include lack of common data elements, such as multiple methods for describing location (e.g., latitude/longitude, legal description), and a diversity of data formats established by researchers maintaining separate databases. With GIS software, the geographic location provides the common link for working with multiple, seemingly unrelated, data sets. Data can be integrated to provide a more comprehensive picture of a phenomenon than would be possible otherwise. Integration facilitates *analysis* of spatial relationships. For example,

information on hazardous waste generators or disposal sites may have been collected with no knowledge of previous or ongoing water sampling programs or geologic studies by other agencies. A GIS can be used to relate these data sets using location as the key. An analysis combining the sampling data, known waste products of specific facilities, and the distribution and properties of geologic materials could be very useful for evaluating a potential source of groundwater contamination and assisting in predicting the movement of the contaminants.

Through data *display* and output, a GIS can effectively communicate information (e.g., study results) to those who need it most. Citizens, political leaders, other decision makers, and scientists all benefit from presentation of maps, diagrams, and other visual displays of data customized to suit different interests and expertise. Information presented on maps is the most common GIS display format. Maps can be produced at a variety of sizes and scales and printed on paper or polyvinyl film, or as color slides. The maps and additional tabular information can be included in reports or public documents to support the decision-making process. For example, the Illinois State Geological Survey used GIS techniques to produce a series of maps for a study on landfill siting in Champaign County, Illinois (ISWDA 1990).

While GIS software provides many capabilities, a functional system also requires computer hardware, trained staff, and a digital database. Many of these requirements can be identified through a detailed assessment of user needs. The choice of hardware is a critical decision. Running GIS software on a personal computer may be sufficient for performing simple analysis on a small database. Users who need to perform complex spatial analyses on large databases will be better served by a computer that has faster processing and larger data storage capabilities. A large GIS, such as the IGIS, requires staff to run the software and the computer systems. New users must make commitments to initial training and continued use of the system. This will require either hiring new staff or reassignment of existing staff. Finally, a functioning GIS needs data, and allowance must be made not only for initial input but for periodic upgrading of databases. Databases vary widely in how fast they change and need to be updated. The costs for data input are substantial, whether the task is performed by in-house staff or contracted to a consultant, or whether the data are purchased in digital form.

ILLINOIS GEOGRAPHIC INFORMATION SYSTEM

The Illinois Geographic Information System (IGIS) was established in 1983 by ENR with funding received from the Lands Unsuitable for Mining Program. This program is funded by the U.S. Office of Surface Mining and is administered in Illinois by the Department of Mines and Minerals. This program paid for the establishment of initial data sets, computer hardware, GIS software, and staff, and it continues to support part of the system.

The IGIS was started as a cooperative effort of five divisions of ENR: the Illinois State Geological, Water, and Natural History Surveys; the Illinois State Museum; and the Office of Research and Planning. A sixth division of ENR, the Hazardous Waste Research and Information Center, became part of the system in 1985. Other state agencies making regular use of the system include the Illinois Department of Mines and Minerals and the Department of Conservation. Demand for the system continues to grow as more people incorporate GIS into their projects. These users contribute data, additional equipment, personnel, and funding to support the IGIS and expand its capabilities and resources.

The IGIS currently consists of a network of hardware located mainly in Champaign and Springfield, Illinois (fig. 3). The GIS software and some of the databases are shared among all agencies. This has resulted in common data formats, reduced user training, and increased interagency cooperation. Several agencies also use specialized hardware and software and maintain project-specific databases on the basis of research needs. For example, the Illinois State Geological Survey uses software packages designed specifically for subsurface geologic investigations. The Illinois Natural History Survey uses remote sensing software for vegetation studies. These software packages provide additional capabilities for specialized applications.

Hardware

The use of the IGIS has expanded steadily since its installation. Decreasing costs of hardware and increasing processing speed and storage capabilities facilitated this expansion. This has made it possible to undertake increasingly complex and time-consuming GIS tasks, making GIS more attractive to potential users. The specific hardware of the IGIS has evolved over the years and will continue to do so as new equipment becomes available and as system requirements change. The IGIS is supported by a variety of hardware, including computers, data storage devices, input and output devices, and communication links.

Computers A general trend in computer usage is that systems are evolving from large centralized multiuser processors toward distributed networks of smaller but increasingly powerful single-user, stand-alone workstations. The current IGIS hardware configuration is in transition between these two configurations. Two types of computers, minicomputers and workstations, support the IGIS. Three Prime minicomputers and several workstations (SUN and Silicon Graphics) currently support the IGIS user community. Each type of computer has its advantages and disadvantages. Minicomputers can serve many users at one time, allowing multiuser access to shared databases. However, supporting many users at one time can also lead to slow response time; several intensive jobs operating at the same time can have a severe impact on system performance. Minicomputers remain useful for occasional users, they help support numerous peripheral devices, and the batch facility allows jobs to be processed during off-peak hours.

Workstations offer capabilities and characteristics that are nearly the direct opposite of minicomputers. Instead of serving a large number of users, workstations generally serve one or a few users, although workstations are available that have the capability to support many users. Workstations offer fast processing, although faster processing speeds are also available in newer minicomputers. For example, workstations now being used by the IGIS have computing

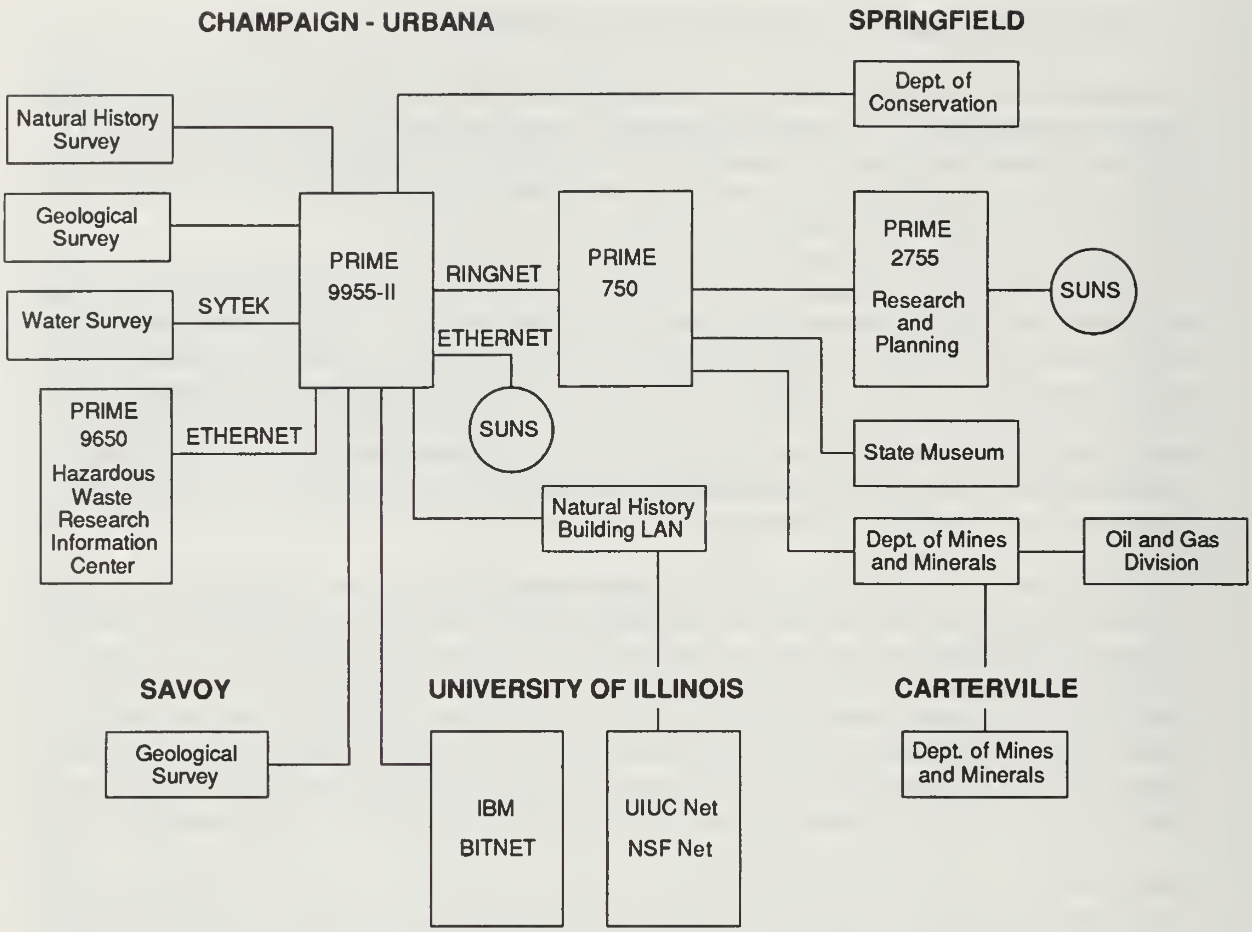


Figure 3 Network of hardware linking users of the Illinois Geographic Information System.

speeds of 12 to 16 mips (million instructions per second), whereas the fastest of the IGIS minicomputers offers computing speeds of about 5.5 mips. These speeds reflect the relative age of the machines and the technological advances being made by computer manufacturers. These features make a workstation a very suitable computing environment for high-priority or intensive interactive tasks and for developing and testing programs. One potential disadvantage of a workstation is that a software license usually must be purchased for each machine. This can result in organizations having to make a larger per-user investment for software.

Data storage Storing digital data requires disk drives and tape drives. Disk drives provide the space for storing and running software, for online data storage, for project work areas, and for batch job processing. As any GIS database develops, more disk space will be required. The IGIS started (in 1983-84) with about 600 megabytes of disk storage on one minicomputer. The disk storage capacity of the entire system, including the minicomputers and the workstations, has grown to more than 18 gigabytes.

Tape drives are needed for long-term data storage, to back up the system, and to load information onto the system. Two tape drive systems are used on the IGIS: one that uses a spool-type nine-track tape at 6,250 bits per inch and another that uses 8-mm videotape as the storage medium. The videotape cartridge, a relatively new data storage mechanism, can hold much more information than a spool-type tape. The increased storage capability, combined with the small physical size of the cartridge, makes videotape an efficient data storage mechanism.

Input and output devices Digitizing boards and keyboards serve most of the data input needs of the IGIS. Digitizing boards provide a mechanism to input graphic map data into a GIS database. The digitizing process and data input are discussed later in more detail. Other options for data input include optical scanning and purchasing digital data from outside agencies or vendors.

Data output options are numerous; many devices can be used to generate maps, tabular listings of data, and reports. Maps are the most common GIS products, and several devices are used for map production, including pen plotters, electrostatic plotters, laser printers, and film recorders. Pen plotters are used to produce color or black and white maps, either on paper or polyvinyl film. An electrostatic plotter provides quality color graphics capabilities and allows production of maps that are more complex and more colorful than maps produced with a pen plotter. However, the purchase and maintenance costs of an electrostatic plotter are substantially higher than costs associated with pen plotters. Also, a climate-controlled environment (temperature and humidity) is needed for efficient operation of an electrostatic plotter. Laser printers can be used to produce black and white maps on letter- or legal-size paper. Cameras are also used as output devices to produce slides or prints. A variety of high-speed, letter-quality printers are used to print tabular lists and reports. Digital output via PostScript is another option.

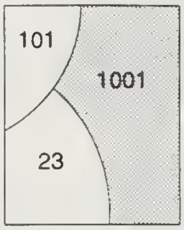
Connections With a large number of users in several locations and a diverse selection of hardware, many types of connections are required, including leased telephone lines, an Ethernet local area network, and dial-in phone lines. Several dedicated leased lines provide off-site access at 9,600 baud to the Prime computers for users in Springfield and Carterville, Illinois. A building-wide Ethernet network has been established within the Illinois Natural History and State Geological Surveys. Ethernet connections on one of the Prime computers, on workstations, and on personal computers provide the capability to transfer information among any of these machines. Several dial-in phone lines also provide access for remote users.

Software

Software provides the data manipulation and analysis capabilities of a GIS. Software portability to many types of computers including mainframes, workstations, and personal computers and compatibility with many operating systems (e.g., PRIMOS, UNIX, VMS, and DOS) has made GIS more accessible to many potential users. During early planning stages of IGIS, several software packages were evaluated on the basis of requirements of the Lands Unsuitable for Mining Program, and ARC/INFO (developed by Environmental Systems Research Institute) was selected.

As the name implies, ARC/INFO consists of two components. ARC is a vector-based system used to compile, manipulate, and store the graphic components shown on a map. The digital map file, called a coverage, may contain four types of graphic information to represent map features: points, lines, polygons, or annotations. INFO is database management software used to store and manipulate the descriptive tabular information associated with the map features. For example, in an ARC/INFO coverage, ARC would manage the locations and display of features included on a map, such as water wells (point features), roads (line features), or urban areas (polygon features). These features would be associated with tabular attribute data (viewed and manipulated with INFO), such as water levels within the wells, road classifications, or land-use categories within the urban areas (fig. 4). Attribute files are related to ARC coverages by unique feature identification numbers. The attribute file can include as much or as little information as needed for a particular application. In addition, multiple attribute files can be related through common data items. ARC/INFO is not restricted to using INFO for database management functions. An interface is available that allows ARC to access information stored in numerous relational database management system packages, such as dBase III or Oracle.

ARC



Item

Area	Perimeter	Cover No.	Cover ID	Stand No.	
30	21	2	101	I-1604	
68	52	3	1001	I-1623	Record
32	19	4	23	I-2004	

INFO

Stand No.	Dom. Species	Age
I-1622	S. Spruce	45
I-1623	W. Hemlock	110
J-2000	W. Spruce	60
J-2001	Deciduous	30

Figure 4 Link between ARC and INFO. The ARC coverage (*left*) consists of polygons enclosing areas of similar tree species. The INFO file stores information concerning the stand number, dominant species, and tree age. The ARC and INFO file information are linked through the common item, Cover ID.

ARC/INFO is designed around a tool box concept that provides a variety of data input, manipulation, spatial analysis, and output functions. The software consists of commands grouped in modules or subsystems that correspond to specialized functions. For example, map and graphic output functions are in the ARCPLOT module and coverage editing capabilities are in the ARCEDIT module. The TIN module contains functions needed to create, store, and analyze three-dimensional surfaces, such as surface topography. Additional TIN capabilities allow contouring and generation of three-dimensional perspective views. These capabilities expand the analytic functionality of GIS to include investigation of subsurface features, such as geologic units. The Arc Macro Language provides additional programming tools for designing applications (e.g., menu-driven interfaces) that can be tailored to the needs of specific users.

Data stored in a variety of formats can be integrated and used by ARC/INFO software. This is important when digital data are acquired and need to be converted into a common format to run on one system. Data exchange formats that ARC/INFO recognizes include U.S. Geological Survey Digital Line Graph (DLG-3), AutoCAD Digital Exchange Files (DXF), U.S. Census Bureau DIME and TIGER files, ERDAS image files, INTERGRAPH files, U.S. Geological Survey Digital Elevation Model (DEM) information, Oracle tables, and others (ESRI 1987).

Efficient data import and export capabilities allow transfer of information to other software programs. ERDAS, a raster-based system, is commonly used to analyze satellite imagery or aerial photography and is installed on one of the IGIS Prime computers, on a personal computer, and on a SUN workstation. A software link provides a mechanism to display ARC/INFO coverages with images displayed by ERDAS. The Interactive Surface Modeling (ISM) and Interactive Volume Modeling (IVM) software packages are running on workstations that are networked with the IGIS. The ISM gridding, contouring, and volumetric calculation capabilities are used for many geologic applications, such as mapping the extent and elevation of subsurface horizons. Information stored as ARC/INFO coverages (e.g., a coverage of county boundaries) can be exported from ARC/INFO and used with products generated by ISM. IVM provides three-dimensional capabilities that allow modeling and enhanced visualization of surfaces generated with ISM.

IGIS Databases

The original IGIS database was designed to meet the needs of the Lands Unsuitable for Mining Program. To support this program, a database was needed that would provide a regional overview of many factors related to coal mining. Other information was needed to evaluate coal mining and environmental concerns at a more detailed scale. There was also a need to

incorporate tabular information. The result was a multilevel database that contains three separate databases: statewide, detailed (or coal-area), and tabular.

The statewide database consists of information for more than 80 map layers or data sets. This information was developed by digitizing or scanning maps at scales of 1:500,000 or 1:250,000. At a scale of 1:500,000, 1 inch equals approximately 8 miles, and a printed map of the state measures approximately 30 by 50 inches. Areas as small as 1 square mile have been captured and are represented as polygons in the statewide database. Features smaller than this size are represented as a point. The statewide database includes maps of bedrock geology, soil associations, natural areas, roads, and many others (table 1). This information can contribute to studies that are concerned with the entire state or a multicounty area. Although these data were generated at a scale too small for site-specific projects, they can be useful for selecting areas for more detailed study. A published index (Greene 1990) contains a variety of information on the statewide database, including coverage names, original map scale, item definitions, and agency contacts.

The more detailed coal-area database was compiled by digitizing maps at scales of 1:62,500 or 1:40,000. This database has five components: strippable coal resources, administrative units, hydrology, infrastructure and special features, and the Integrated Terrain Unit (ITU). The strippable coal resource database contains information for major surface-minable coal seams in the state, defined as coal that occurs less than 150 feet below the ground surface. The coal resource information was digitized from 1:62,500-scale maps published by the Illinois State Geological Survey and has a minimum polygon resolution of 10 acres. Approximately 30 percent of the state is covered by this mapping, mostly in southern and western Illinois (fig. 5). Specific information includes the extent and thickness of coal members, overburden thickness, coal resource reliability class, and other features affecting minability, such as areas where coal is absent. The Illinois State Geological Survey uses this information extensively in support of its coal research and service programs.

The ITU coverage incorporates features from several map layers at a scale of 1:40,000, including soils, slope, landforms, wetlands, and vegetation types. Although the extent of this mapping is limited to an area in southern Illinois (~5% of the state; fig. 5), the ITU data are quite detailed—the minimum polygon resolution is 3 acres. The ITU method involves manual integration of multiple data layers by matching or adjusting common boundaries from various source maps before the maps are digitized (Dangermond 1976). For instance, a soil unit and a landform may actually be bounded by the same line that is shown slightly differently on two source maps. With the ITU approach, the difference between these two lines is resolved and only one line is input. When manual integration is complete, the attribute files consist of several items that are coded for each of the multiple elements. This information was prepared to assess the effects of surface coal mining.

The information in the detailed surface hydrology, administrative units, infrastructure, and special features databases was compiled at a scale of 1:62,500 for several 15-minute quadrangles (fig. 5). The surface hydrology data include information on flood hazard boundaries, seeps and springs, stream order, river mileage, stream condition, stream monitoring stations, and other factors. Administrative unit information includes county FIPS (Federal Information Processing Standard) code, state reserve system units (e.g., state parks, conservation and wildlife areas), county, local, and private parks, incorporated areas and census tracts. The infrastructure and special-features data include roads, trails, railroads, pipelines, transmission lines, airports, cemeteries, schools, and escarpments.

Tabular information is also an important part of the IGIS database. One example is the basic well data file, a compilation of data on more than 300,000 wells drilled in Illinois, including

Table 1 Statewide data sets on the Illinois Geographic Information System (scale 1:500,000)

Geological Data
- Bedrock geology
- Quaternary (surficial) geology
- Glacial boundaries
- Soil associations (includes parent material)
- Stack units
- Structural features
- Escarpments
- Thickness of loess
- Thickness of glacial drift
- Thickness and depth of Springfield Coal
- Thickness and depth of Herrin Coal
- Limit of Pennsylvanian System

Water Resources Data

Locations:
- High groundwater-yield areas
- USGS stream-gauging stations
- USGS observation wells
- USGS/IEPA water-quality stations
- ISWS instream sediment-monitoring stations
- ISWS potential reservoir sites
- ISWS mass groundwater measurements
- ISWS lake and reservoir sedimentation survey sites
- ISWS surface water-withdrawal intakes
- ISWS observation wells
- ISWS dam-safety survey sites
- ISWS sanitary-discharge points
- Piezometric surfaces

Classification of streams for:
- USGS river miles
- USGS WATSTORE number
- USGS cataloging units
- USEPA STORET number
- USEPA hydrologic reach
- River entry, terminus, confluence, and exit points
- Stream situation
- Stream low flow
- Stream elevation
- Illinois public waterways
- Corps of Engineers navigable waterways
- Channelization and canalization
- IDOT drainage basins

Biological Data
- Natural divisions
- Soil associations
- Soil Conservation Service land resource areas
- Ecoregions
- Potential natural vegetation
- State natural areas
- Chemical and physical characteristics of soils
- Forest/prairie distribution of 1820

Infrastructure Data
- Incorporated settlements
- Major airports
- Major air navigation facilities
- Oil and gas pipelines and related facilities
- Existing roads
- Existing railroads
- Abandoned railroads
- Existing transmission lines
- Commercial boat docks
- River locks

Administrative Data
- County boundaries
- State Reserve System units
- Federal Reserve System units
- Special federal reserves
- Inventory of public recreation sites
- Electric Utility Service areas
- Soil and water conservation districts
- Regional port districts
- State representative and senatorial districts
- Federal congressional districts
- USGS geographic place names
- U.S. census data
- Bureau of Economic Analysis income files

Climate Data
- ISWS long-term stations
- Temperature maximum/minimum
- Evaporation
- Precipitation

Abbreviations: USGS, U.S. Geological Survey; IEPA, Illinois Environmental Protection Agency; ISWS, Illinois State Water Survey; USEPA, U.S. Environmental Protection Agency; IDOT, Illinois Department of Transportation.

water wells, oil and gas wells, engineering borings, and others. Information in this file includes location, well type, and well history. Other tabular data sets include a state landfill inventory, information on waste generators, chemical data on coal quality, and stratigraphic descriptions of rock units recorded in wells.

Several project-specific databases have been developed. The scale and extent of this mapping depends on each study. Some project-specific mapping coverage is statewide, whereas other

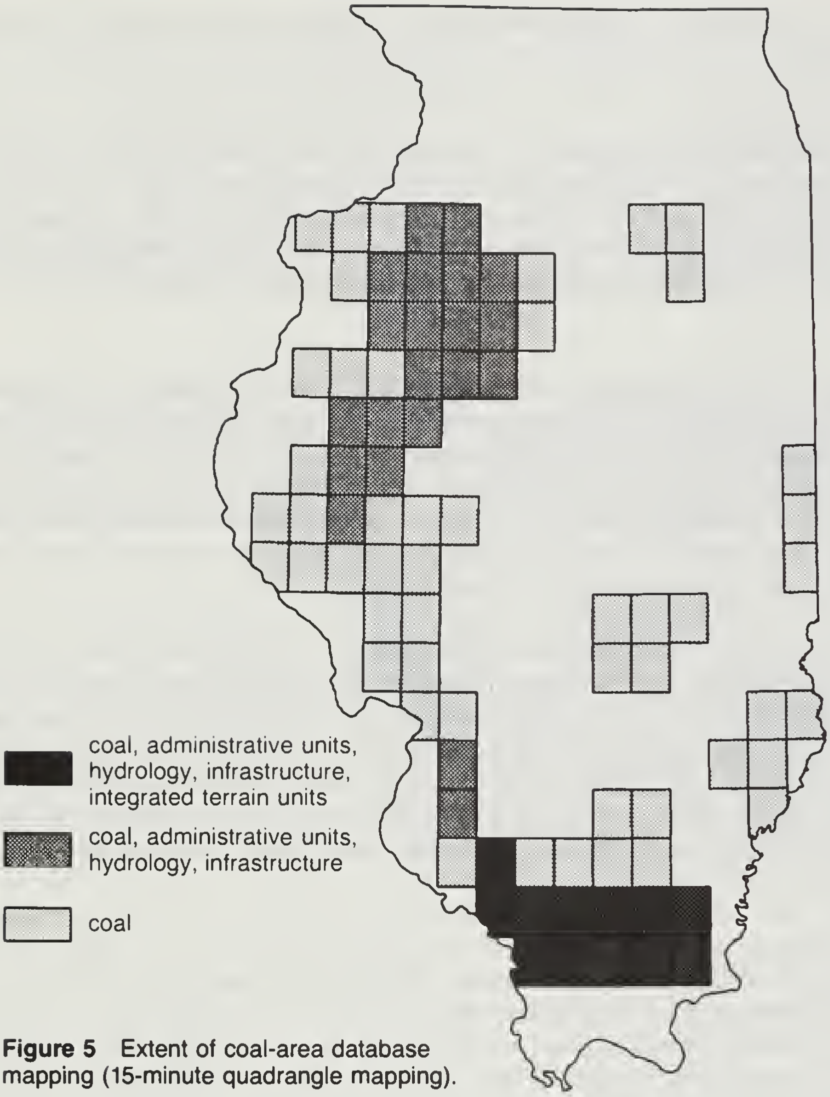


Figure 5 Extent of coal-area database mapping (15-minute quadrangle mapping).

efforts focus on small areas. Project-specific data sets produced on a statewide level include the Illinois component of the National Wetlands Inventory and the coal mine database. The wetlands database was developed in cooperation with U.S. Fish and Wildlife Service and was funded by the Illinois Department of Conservation. It contains location and classification information for wetlands and deepwater habitats. Areas as small as 1/10 acre are recorded in the inventory. The coal mine database consists of information on areas where coal has been mined by surface and underground operations. This information is useful for planning purposes, because collapsing underground mines can cause the ground surface to subside, resulting in damage to structures, roads, and utility lines.

Other project-specific data sets have been developed for smaller areas of the state. Geographic extent, input scale, and level of detail vary depending on the data needs of each project. Multicounty or regional projects that have contributed substantial databases to the system include the effort to site the Superconducting Super Collider in northeastern Illinois and a study that involves geologic mapping and assessment of the mineral potential in the part of Illinois south of 38° north latitude. More detailed projects include initial analyses of landfill-site suitability for several counties, shoreline mapping along Lake Michigan, a historic inventory of hydrologic and land-use features in the Lake Calumet area of northeastern Illinois, and a

database on coal mines and mine permit areas in southern and western Illinois. Each project has contributed data that are part of an ever-increasing volume of coverages for many parts of the state.

When no digital data are available for a particular project or when existing data do not specifically meet project needs, information must be acquired and input into the GIS. Two ways in which this may be done are to digitize information from maps and to purchase data sets that are already in a digital format. The method appropriate for a given project depends on the scale of the project, the amount of additional data to be acquired, and available funds.

Staff

Without people to use and support a system, the best software, the fastest computer, and the most sophisticated database mean little; people are the most important component of any GIS. Staffing requirements vary depending on the size of the system, i.e., the types of computers and other hardware, the size of the databases, the number of users and sites, and user requirements. For a facility like the IGIS, which has many users at several sites, a large staff is required to provide functions such as system administration, programming, data compilation, quality control, training, and applications development.

The people working on the IGIS can be divided into two groups: a smaller central core of system staff and a larger group of users. The system staff consists of a database administrator, technical support staff, and programmers who run and maintain the main Prime computing system and support the evolving workstation network. Two programmers and a technical support specialist are responsible for the daily operation of most of the main hardware: two minicomputers and all peripheral equipment (e.g., disk drives and communications hardware). A database administrator coordinates the use, acquisition, and documentation of many shared data sets.

The user community accesses the system from several sites, and the number of users, their responsibilities, and specific applications vary within each agency. Most agencies using the IGIS have staff that perform several functions, including data entry, map digitizing and editing, training, programming, consulting, system management, quality assurance, and project management. Some divisions have staff dedicated to one task, such as data entry, but most staff members perform several functions. Some staff work full time with the system, and others have additional responsibilities and work part time with it.

The experience and background of ENR staff working with GIS vary. Before working with the IGIS, most staff members lacked any specific training in GIS methods. Most users are scientists, trained in such disciplines as geology, archaeology, or biology, who have learned GIS techniques through training classes, short courses, and hands-on applications. When working with GIS, the knowledge of a particular discipline is coupled with an understanding of mapping principles, geographic analysis, and computer systems. A desirable background for any GIS staff would incorporate some experience from each of these areas of expertise.

OPERATIONS OF THE GEOGRAPHIC INFORMATION SYSTEM

The four basic GIS operations are data input, quality control, data manipulation, and data output. A GIS operates with digital data and information that commonly must be transferred from paper maps or other digital sources. Quality control procedures, often much more stringent than those applied to manual map products, must be used to ensure the integrity of the resulting digital database. Once all map information has been entered, a GIS is capable of sophisticated data manipulation and analysis using a variety of automated processes. Output and display of GIS data provide the visual products that summarize the results of the analysis.

Data Input

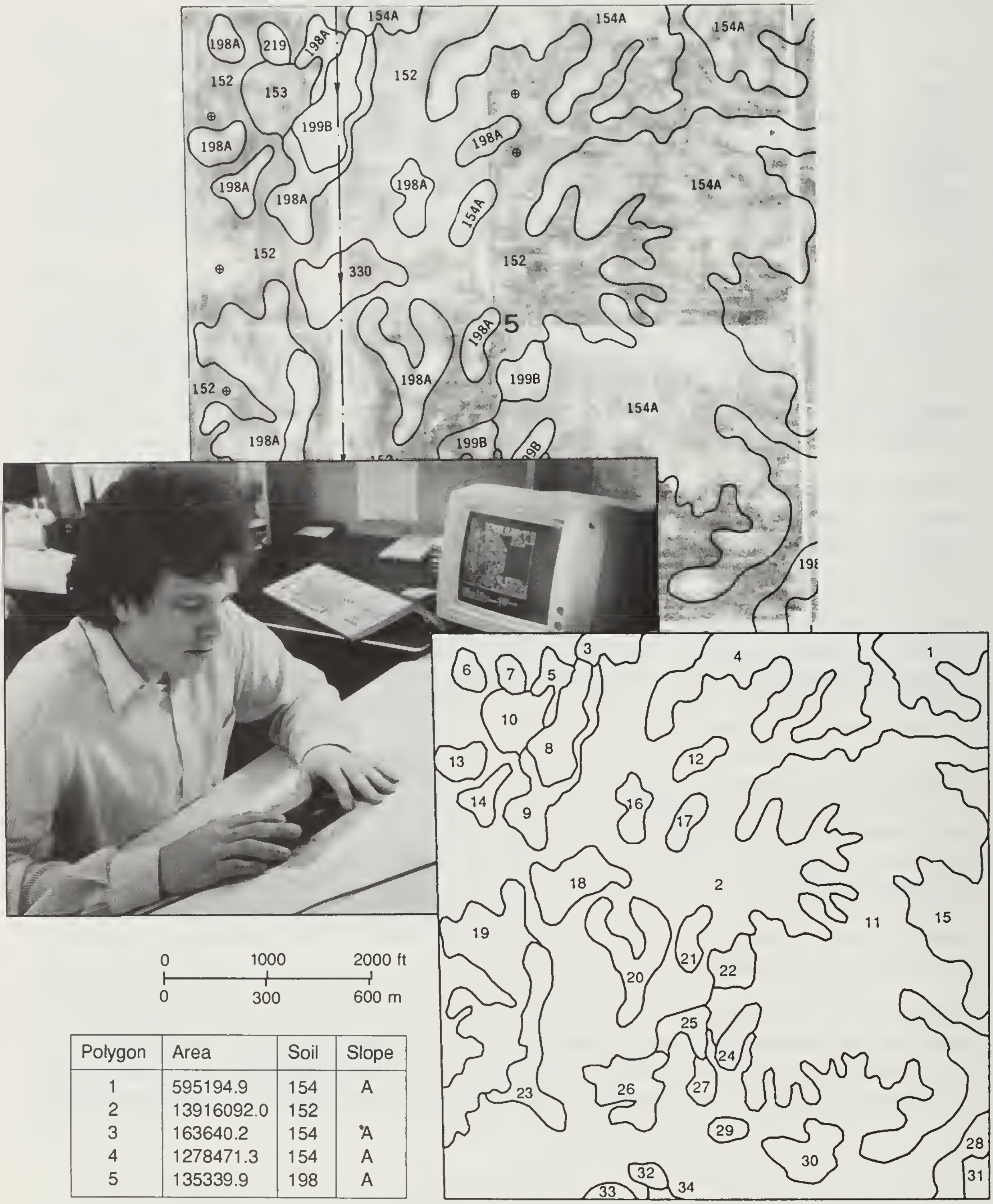
A variety of methods are available to input graphic elements—the points, lines, and polygons that make up a map—into the GIS. These methods include scanning, digitizing, and generating coverages from tabular data. Each of these techniques has advantages and disadvantages, and all have been used to some extent with the IGIS. The appropriate input method for a given project depends on the scope of the project, the amount and type of data to be input, and staff availability.

Scanning techniques involve reading a map with an optical scanning device. A software program converts the scanned map information directly into a GIS data file. Scanning is efficient for the transfer of graphic elements from particularly complex maps, especially when the scanned copy is carefully prepared, clean, and not cluttered with extraneous information. For example, maps with many gray shades, faint lines, or lines that are close together may not scan well and may require manual error correction. Attribute information and scanning errors must be corrected or entered by hand. The costs for scanning equipment and services are relatively high compared with manual digitizing, but may be justified by project time constraints. As scanning technology evolves, it should become more cost effective and may replace much of the manual digitizing, which is presently the most common data entry technique at ENR.

Manual digitizing can be thought of as electronic tracing of map features. With a map mounted on a digitizing board, an operator uses a cursor to trace map features while inputting locations by depressing keys on the cursor. The cursor acts as an electronic transmitter that generates signals indicating relative locations of features being digitized, while the digitizing board acts as a receiver that tracks the position of the cursor as it is moved across the map. The GIS software records the pattern of signals as feature shape and location data. Figure 6 illustrates a typical example of the steps involved. The attribute data describing the automated maps may be input at a terminal keyboard or from the cursor.

A third way to create geographic map coverages is to use the software to generate features from location information in a tabular data file (e.g., a tabular file containing location coordinates, such as latitude and longitude). This method is used most frequently to generate point coverages, although line and polygon features can also be created using coordinate geometry to enter legal descriptions and survey traverse data.

Digital geographic information may also be purchased from government agencies and private vendors. These data, already converted into digital form, are typically available on magnetic tapes, diskettes, or optical disks. The U.S. Geological Survey produces Digital Line Graph (DLG) files at various scales. DLG files of transportation and hydrography at the 1:100,000 scale are available for much of the nation. The U.S. Geological Survey Digital Elevation Model (DEM) product consists of regularly spaced points of elevation information that can be used to generate a GIS coverage representing surface topography. Many private companies sell satellite imagery and other data in raster format. This information is collected using a variety of methods; the feature resolution varies depending on how the data were collected. Use of these



Polygon	Area	Soil	Slope
1	595194.9	154	A
2	13916092.0	152	
3	163640.2	154	A
4	1278471.3	154	A
5	135339.9	198	A

Figure 6 Steps in producing a GIS map. (*top*) Part of a soil map published by the Soil Conservation Service. (*center*) GIS operator digitizing lines from the soil map; other information (e.g., soil type, slope class) is input at a keyboard. (*bottom*) The GIS product, which consists of two automated files, a graphic map file and a tabular attribute table.

data can be cost effective if the scale of the source data is appropriate to the scale needs of the project. Most GIS packages have the capability to convert many types of data (e.g., DLG, DEM, or CAD design files) into a common format.

Data Quality

Quality control considerations begin before data entry and continue through to the delivery of final GIS products. Although critical to any transfer of information into a computer, quality control associated with geographic information raises unique challenges. Automated map data can be only as accurate as the source maps from which they are digitized or otherwise obtained. Unless errors in content or scale are identified and corrected before automation, these will be replicated in the GIS coverage. The stability of the base map medium is particularly important during the data input stage. For example, maps drafted on a polyvinyl base are preferred for digitizing because this material is much more stable than paper. Paper maps can expand or contract significantly with changes in room humidity.

Map scale is a very important consideration when working with maps produced from a GIS. With a published map, data usually are available only at the scale at which they are presented. Photographic enlargement for use at a larger scale results in an obviously rescaled product. Changing the scale on a GIS map is a matter of a single command, and data can be enlarged with less obvious, often imperceptible, distortions. Because the quality of a GIS map is dependent on the scale at which the original data were input, a map digitized at a scale of 1:100,000 (1 in. = ~1.5 mi) will probably not produce a valid map if its information is expanded to a scale of 1:24,000 (1 in. = 2,000 ft). The density of information varies with scale; data shown on maps at a scale of 1:100,000 are much more general than data shown on maps at a scale of 1:24,000. GIS data should be used at or near the original input scale.

After a map is digitized or entered into a GIS database, several quality control steps are necessary to ensure an accurate conversion into the digital format. One of the first quality control steps is to check the contents for completeness and accuracy. Have all the features been digitized? Was anything missed in the digitizing process? Are the features in their proper locations? These questions must be considered as the digitizing progresses and verified upon completion of the task.

A common quality control problem involves errors in attribute input, entry of the information associated with the points, lines, or polygons on the map. This information is usually input by a keyboard operator, and typing errors may occur. To check for these sorts of errors, several GIS operations are available. One such operation sorts through all the attribute data, checking for valid values. Other operations involve determining that each polygon is represented by the correct code in the attribute table. These types of quality control procedures are time consuming but necessary to ensure the integrity of the database and the products.

Data Manipulation

One of the main strengths of a GIS is its ability to conduct sophisticated operations on existing data to produce "new" information. These operations include overlay and analysis functions that allow a user to combine multiple data layers to create project-specific maps and tabulations of data. Descriptive attributes are preserved and carried throughout the overlay process so that each map feature can have multiple attributes. Examples of data extraction, buffering, and overlay functions are given below to highlight the power and flexibility of these GIS functions. Overlay functions include a series of operations that specify the content of the resultant map coverage. Following standard definitions, these include union, intersect, and identity. In each, the area to be preserved and the attributes to be retained and combined are specified in the

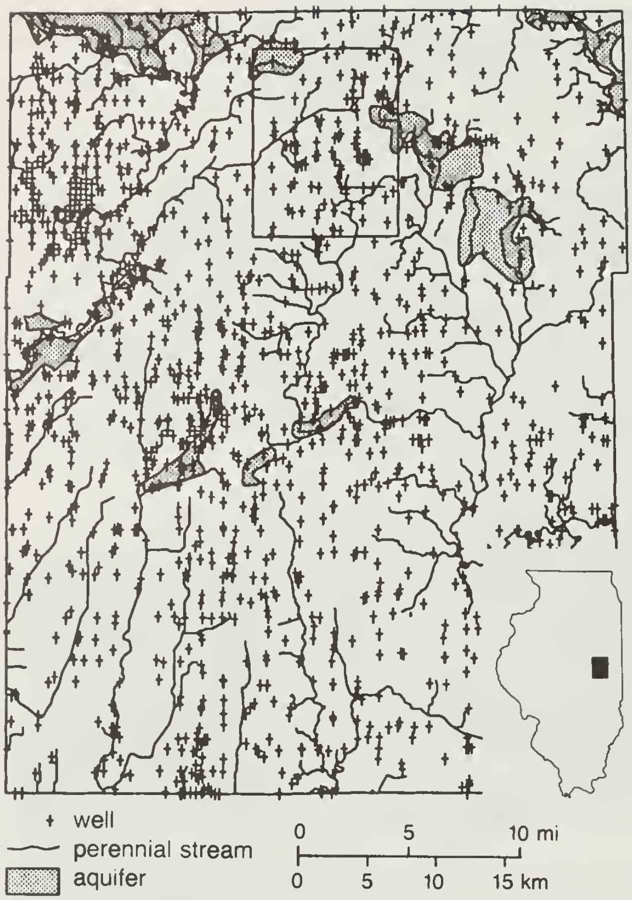


Figure 7a Champaign County, Illinois. Shown are most wells in the county, perennial streams, and some aquifers. Rectangle (*top center*) represents the Rantoul 1:24,000 quadrangle.

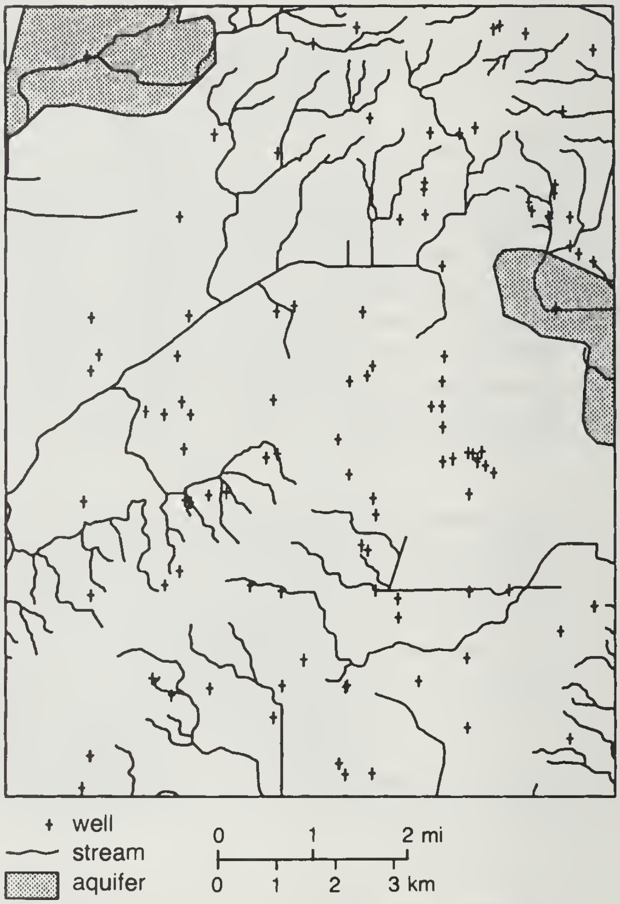


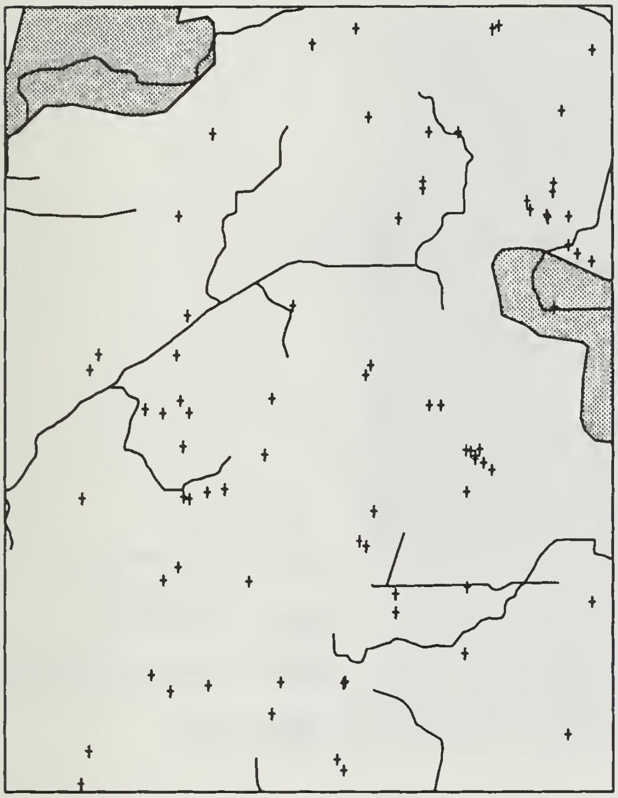
Figure 7b Clipping procedure. The Rantoul quadrangle was used as a "cookie cutter" to select only the data that fell within its borders. Wells, aquifers, and all streams within the quadrangle are shown.

overlay operation. Attributes of coverages also can be manipulated by means of editing routines or changed with mathematical operations available in database management systems.

Data extraction Several GIS operations facilitate extraction of specific data from a coverage. One commonly used form of data extraction involves removing a smaller geographic area of interest from a larger data set (fig. 7a). This procedure, analogous to a using a cookie cutter, is called data clipping and is used to extract data for only the area of interest. In figure 7b, data from the statewide database, including wells, aquifers, and streams, have been extracted and plotted for the area of the Rantoul quadrangle in north-central Champaign County.

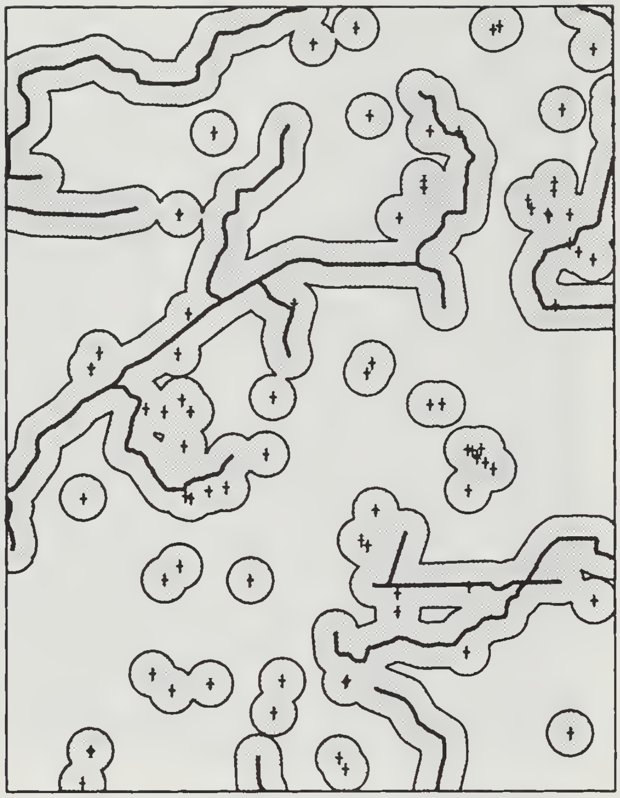
Another commonly used form of data extraction involves selecting data meeting specific criteria. For a study on water resources, a map might be needed showing perennial streams, aquifers, and all water wells drilled in an area. The GIS can be used to identify all the areas that meet these criteria, creating a "new" data set that can be used for further study. This data selection process is illustrated in figure 7c. From the data sets consisting of all streams, all wells and borings, and aquifers in the Rantoul 7.5-minute quadrangle, only the perennial streams and the water wells have been selected for plotting.

Buffering Buffering involves determination of proximity to a feature or many features, and is generally used to create zones around existing data. For example, wellhead protection



+ water well
perennial stream
aquifer

Figure 7c Reselection procedure. Of all the wells and borings in the Rantoul quadrangle, only the water wells were chosen. Of all the streams, only the perennial streams were chosen.

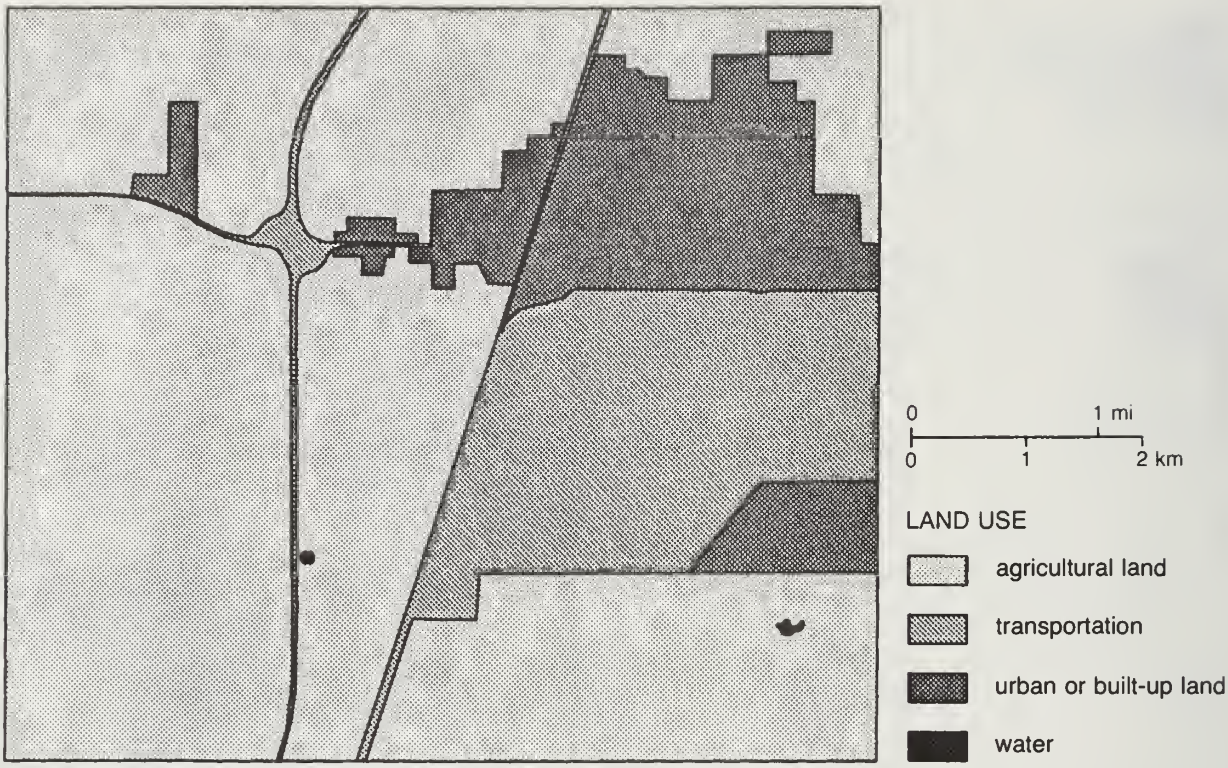


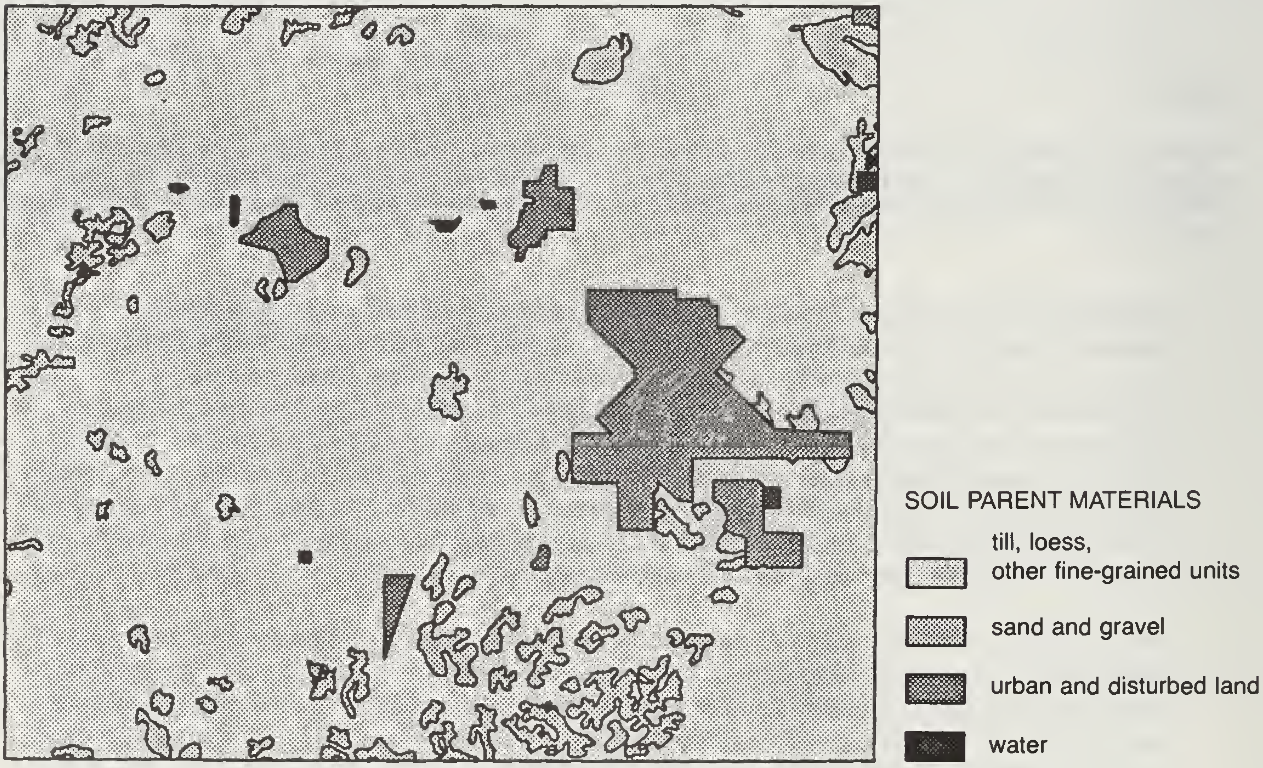
+ water well
perennial stream
buffer zone

Figure 7d Buffering procedure. A 1/4-mile buffer zone (*shaded*) was placed around the perennial streams and the water wells. Note merging of buffer zones where two or more features are close together.

programs may require the creation of setback zones around wells used for public water supplies; setback zones are areas within a specified distance of the wellhead in which activities potentially hazardous to groundwater quality are restricted. In some areas, construction or development may be limited within a certain distance from streams. Distance limitations are also enforced for certain surface and underground mining activities. The buffer function of the GIS can be used to create zones around selected features to identify the features that fall within (or outside of) the area of interest. In the example of buffering shown by figure 7d, the GIS has created a buffer zone of 1/4 mile in radius around all perennial streams (line features) and water wells (point features) in the Rantoul quadrangle.

Overlay techniques Data from several diverse sources commonly need to be used for a specific project. For example, a project may require identification of soil types contained in each land parcel in a county. Here, data coverages containing soil types within the county and land parcels within the county can be overlain, producing a new data set of the soil types found in each parcel. Figure 8 shows a similar example of the overlay process with land use and soil parent material overlain to create a new map showing combined land use and soil parent material. Note that multiple attributes are associated with each area on the combined map.


0
1 mi
0
1
2 km
LAND USE
agricultural land
transportation
urban or built-up land
water


SOIL PARENT MATERIALS
till, loess, other fine-grained units
sand and gravel
urban and disturbed land
water

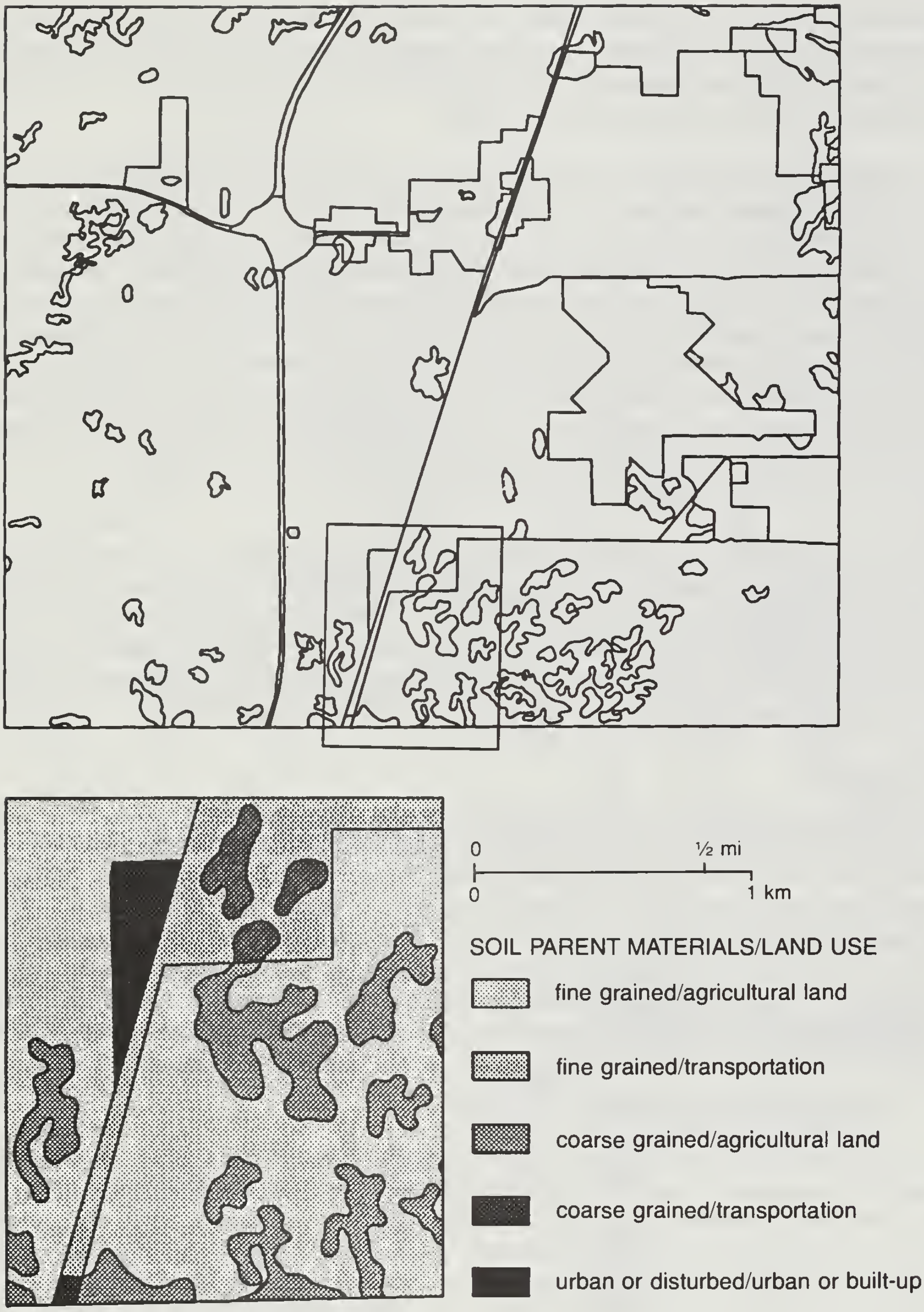


Figure 8 Land use and soil parent materials in part of the Rantoul quadrangle. (*top left*) Land use. (*bottom left*) Soil parent materials. (*above*) Overlay of soil parent materials and land use.

Attribute modeling When coverages are overlain, the data for multiple attributes can be manipulated or modeled to derive new information. The following example was developed for a study that used GIS techniques to evaluate the potential for damage from subsidence caused by underground mines (Treworgy et al. 1989).

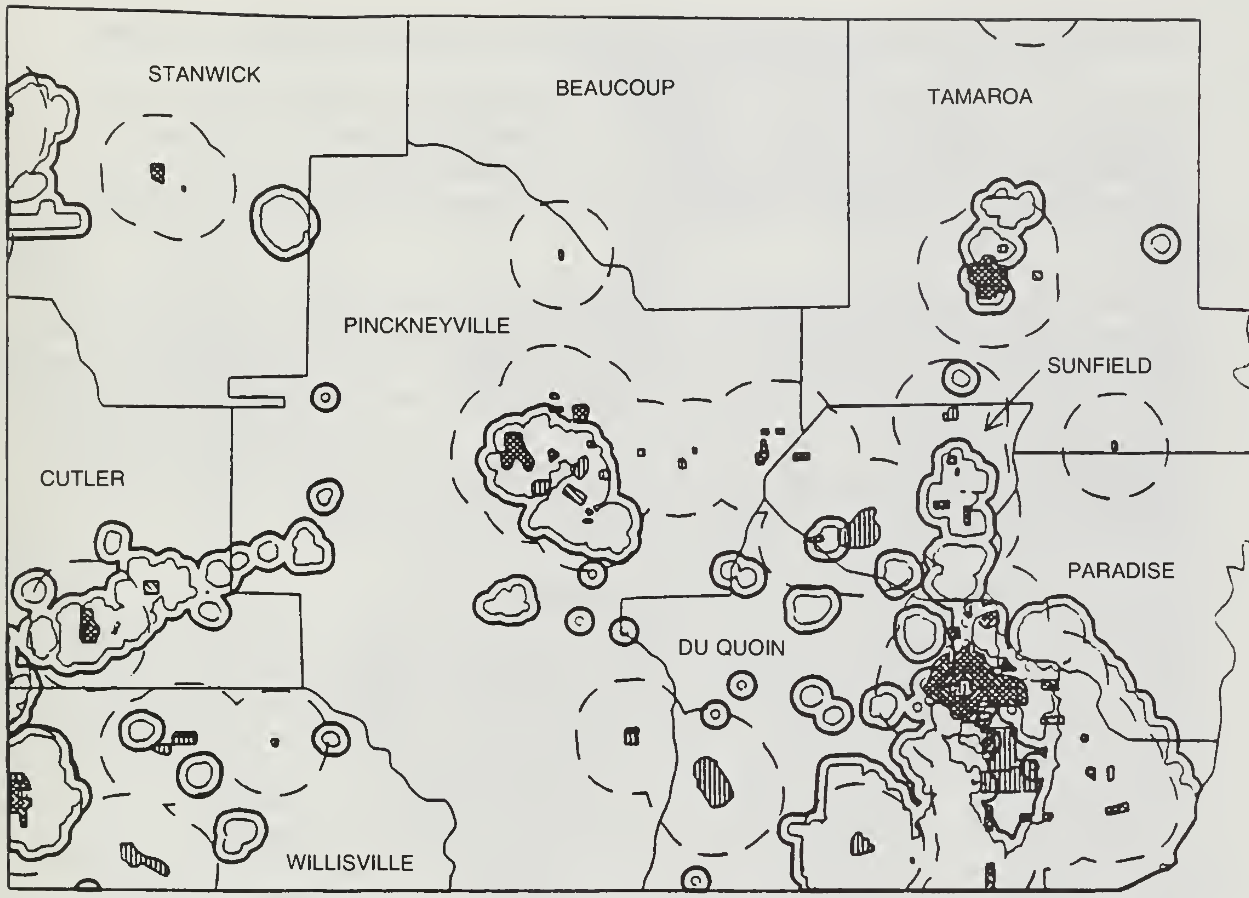
Mine subsidence is the sinking of the ground surface caused by the collapse of an underground mine. In urban areas, surface ground movements caused by mine subsidence can result in considerable damage to structures and other facilities. One part of the study involved estimating the number of housing units over or near underground mines. This was accomplished using GIS techniques to overlay four data sets: underground mine boundaries, land use, census units, and tabular census data. Two buffers of 500 and 1,000 feet were established around mine boundaries to delineate risk zones that could be affected by mine subsidence (fig. 9). Five land-use categories were used: residential, other urban, urban buffer, nonurban, and water. All land-use categories were based on a U.S. Geological Survey land-use data set except the urban buffer, which was created using the GIS. Information on the number of housing units in a census unit was taken from the 1980 census data.

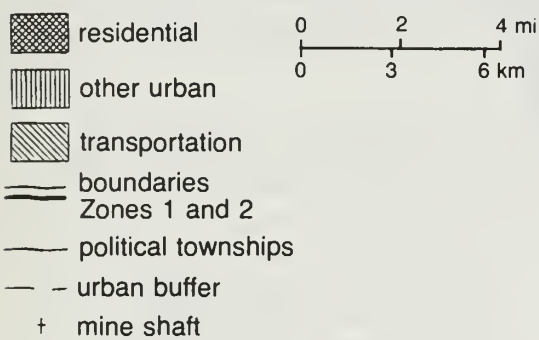
After the census units were overlain with the land-use and mine information, two steps were used to determine the number of homes over or near underground mines. First, the number of housing units in a census unit were apportioned to different land-use categories in that unit. Then, the percentage of each land-use category that was undermined was calculated. The results can be used to summarize various relationships between the four data sets, such as the number of housing units within the 500-foot mine boundary buffer (fig. 9).

Data Output

Since GIS is a map-oriented information system, the production of maps is one of the better known GIS capabilities. Most systems offer a wide range of cartographic tools that allow production of maps with legends, scales, north arrows, annotation, and other graphic elements. Graphic libraries of line types, shade patterns, point symbols, and text styles are included with most software. Users can also design custom graphic symbols for specialized applications. GIS maps can be produced using a variety of output devices including pen plotters, electrostatic plotters, laser writers, other PostScript devices, and film recorders. A variety of map products can be generated on these devices including black and white and color paper maps, polyvinyl maps, slides, and prints. Files can be converted to PostScript formats and used to generate color separates for high-quality offset printing.

Data output can also be in the form of printed lists of tabular information. This information can be summary statistics of information shown on maps, or other data organized in a report format. Another important output function is the ability to convert coverage and attribute information to files that can be used by other mapping or database management software. This capability allows GIS information to be used by other groups and agencies that use other types of mapping software, such as CAD systems. Transfer of GIS information between different types of computers (micros, mainframes, workstations) is an additional data output function. With this capability, coverages and tabular data can be created or compiled on one machine and used with the same software on another type of computer.





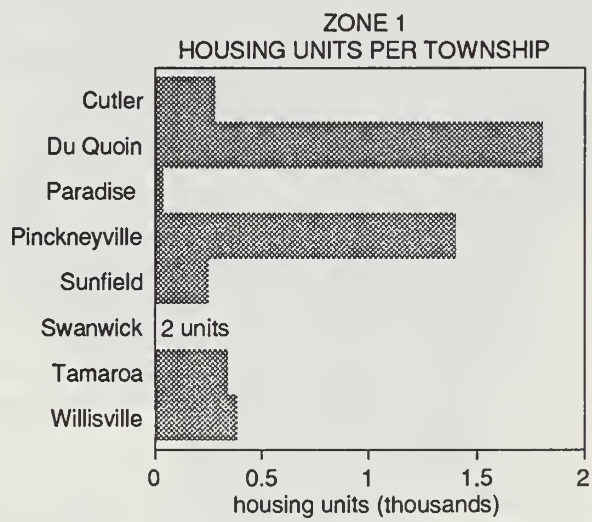


Figure 9 Perry County with mine buffers, land use, and townships. Zones 1 and 2 are 500- and 1,000-foot buffers around underground mines. Table (*right*) shows number of housing units in zone 1 per township.

EXAMPLES OF GEOGRAPHIC INFORMATION SYSTEM APPLICATIONS

Since the IGIS was established at ENR in 1983, it has become an important part of ENR's operations. The system is used daily by geologists, biologists, hydrologists, engineers, archaeologists, planners, and other professionals for ongoing projects as varied as mapping mineral resources, identifying habitats of endangered species, and assessing sites for the disposal of hazardous waste.

In this section, three ENR projects are discussed in which the IGIS played a key role. These were chosen to illustrate a variety of uses and the range of scales at which the IGIS has been used successfully. At the statewide level, several factors were used to compile a map showing seismic risk zones in the state. At the county level, GIS techniques were used to support a landfill siting study in Champaign County. And at the local level, the GIS was used to locate the optimal site in Kane County as part of the Illinois bid for the Superconducting Super Collider, a large, high-energy physics facility. Each study required a unique approach using data at different scales of resolution, reflecting the specific needs of the projects.

At the State Level: Earthquake Intensity Mapping

As part of a study to identify potentially suitable areas for a low-level radioactive waste disposal site, several exclusionary factors were mapped, among them earthquake intensity. An earthquake scenario for the New Madrid Seismic Zone was used to determine the exclusionary areas. Specifically, the exclusionary areas were zones with a maximum intensity value of IX on the Modified Mercalli Intensity Scale (MMIS) on either bedrock or unconsolidated glacial materials or zones with a maximum intensity value of VIII on other unconsolidated deposits. The MMIS is based on descriptive reports of personal reaction, property damage, or land surface disturbance. The intensity values range from I (barely detectable) to XII (catastrophic). Earthquakes of IX on the MMIS are described as ruinous and VIII as destructive. For this mapping effort, intensity was assumed to increase by 1 unit for unconsolidated deposits compared with bedrock.

Zones with maximum intensity values of VII through IX on the MMIS were calculated for a worst-case scenario earthquake (fig. 10). These intensity zones were merged with information selected from the Quaternary deposits map, one of the layers in the statewide database. In most areas of Illinois, the Quaternary deposits, mostly of glacial origin, represent the near-surface geologic units. The units selected from the Quaternary map are the unconsolidated materials judged to be the most sensitive to earthquake shaking and include fine-grained lake deposits, stream deposits (alluvium), and thick loess, a silty windblown deposit. GIS overlay capabilities were used to merge the intensity zones and the glacial materials information to produce the earthquake intensity zone map. This combined map shows areas where unconsolidated deposits may be more susceptible to ground shaking and damage from an earthquake. This map was used as one of several input parameters for identifying areas to host the disposal facility.

At the County Level: Siting a Landfill in Champaign County, Illinois

In 1989, the Champaign County Intergovernmental Solid Waste Disposal Association approached ENR about using the IGIS to assist in a county-wide screening study. The objective of the study was to locate areas where geologic and hydrologic conditions indicated an acceptable site for a landfill.

To facilitate the screening of geologic siting criteria, Illinois State Geological Survey staff developed an innovative mapping procedure, called "slice mapping," using the analytical capabilities of the IGIS. This technique involves mapping the three-dimensional distribution of

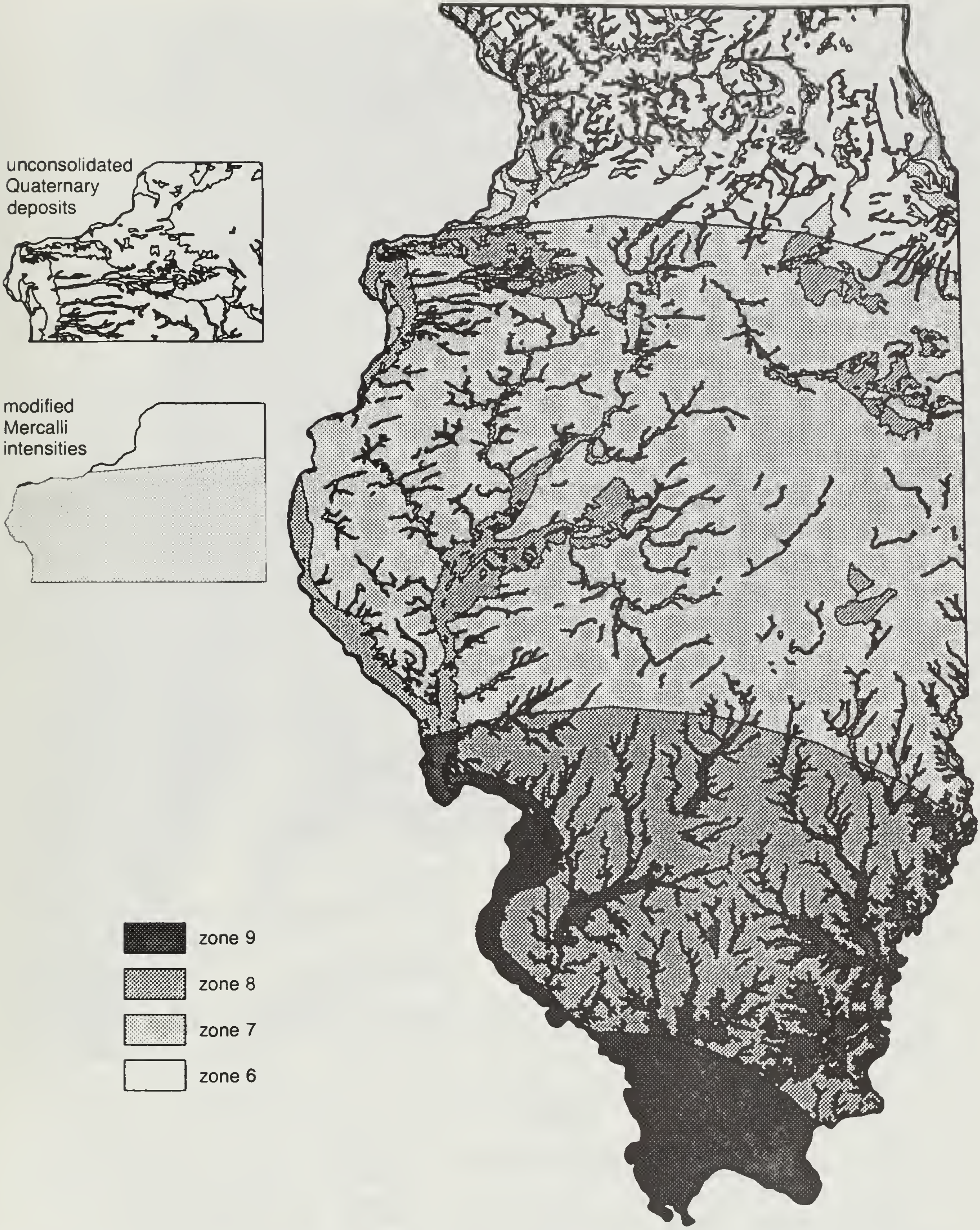
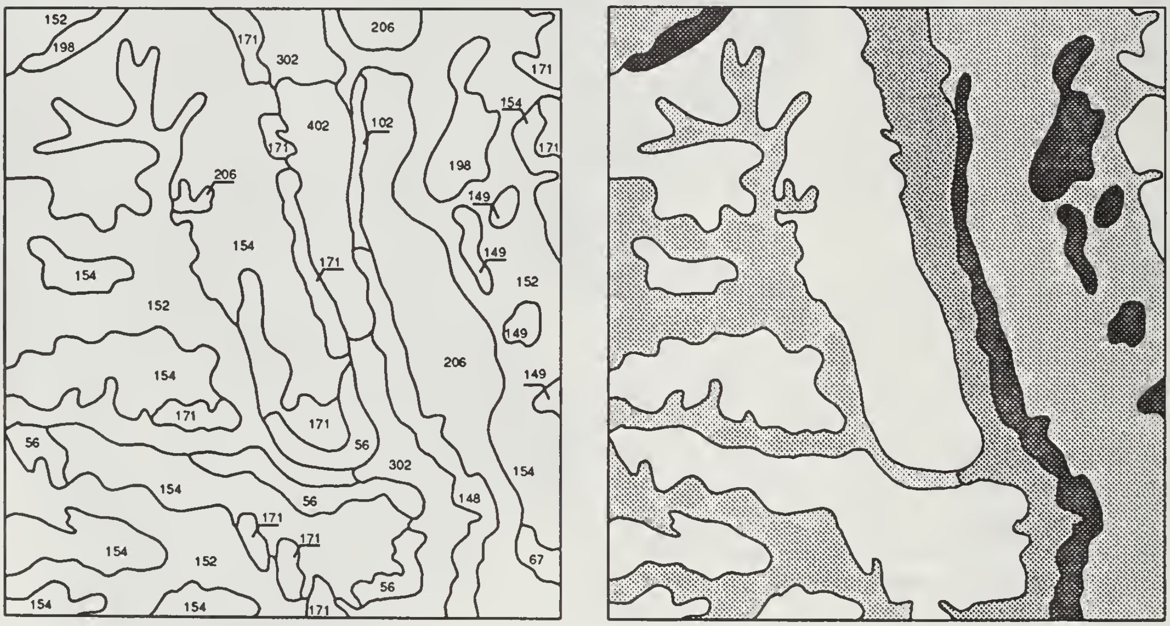


Figure 10 Modified Mercalli Intensity Zone map developed by overlaying unconsolidated Quaternary deposits on calculated intensities. (Note: for the low-level radioactive waste facility siting, all areas within intensity zone 9 were considered unsuitable, regardless of geology. Within intensity zones 6, 7, and 8, intensities were assumed to be enhanced by a factor of 1 intensity value in areas underlain by the relatively loose, unconsolidated deposits.)

geological materials. Geologic deposits in Champaign County consist of up to 400 feet of lithologically variable deposits, including glacial till, sand, gravel, fine-grained glacial material, lake deposits, alluvium, and windblown silt. The distributions of these materials below the surface are complex and need to be evaluated before a landfill is sited. A main goal of the landfill siting study was to avoid areas underlain by sand and gravel, which in Champaign County is a potential source of groundwater.

Two major sources of information were used: detailed county soil survey maps and tabular information about sediments encountered during the drilling of over 3,000 wells in the county. The analytical functions of the GIS allowed the soil information to be manipulated to produce maps of shallow geologic materials (fig. 11), land slope, and poorly drained soils. In addition, the information contained in the well records was used to map the types and distribution of sediments below the surface (fig. 12).

The resultant maps, when combined with maps of many other factors, proved valuable for identifying potentially suitable areas for landfill development. In particular, the analysis of the distribution of geologic materials was used to distinguish areas underlain by sand and gravel deposits from areas of thick, fine-grained, glacial till deposits. For this landfill siting, areas underlain by thick glacial till were rated as more geologically and hydrologically suitable.
In county-level siting studies such as this one, the GIS allowed data from a variety of sources to be readily combined and analyzed. The GIS was used to quickly compile this variety of



Relate Table

Soil	Parent Material	Class
56	loess over loam material	1
67	loess over till, sand or gravel	2
102	loess over sand or gravel	4
302	alluvium	3

loess over loam till

loess over till or sand or gravel

alluvium

loess over sand or gravel

0 1000 2000 ft

0 300 600 m

Figure 11 Relate table used with the dissolve function to create a new map from existing data. In this example, soil parent material information from a Champaign County soil map (*left*) was used to produce a map of shallow geologic materials (*right*).

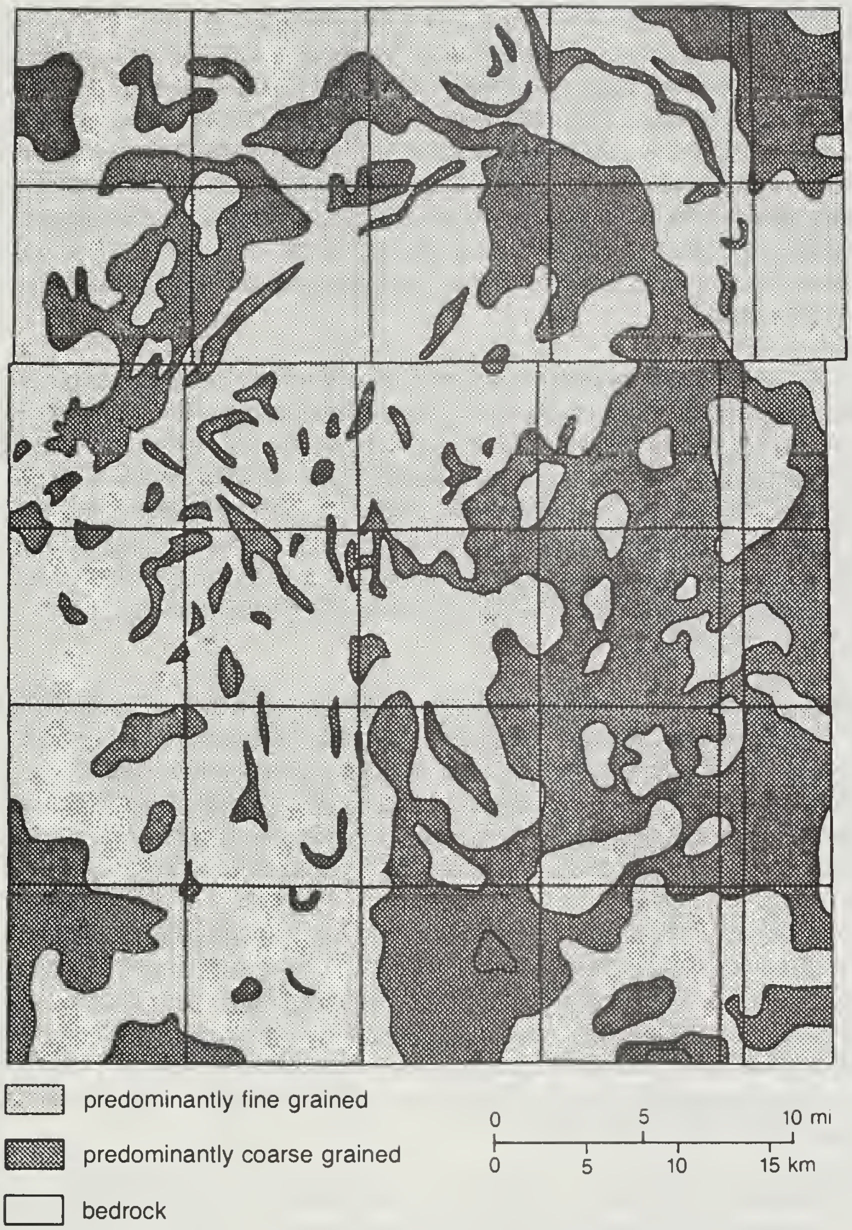


Figure 12 Slice-unit map for Champaign County showing the lithology of the glacial deposits from 60 to 75 feet below ground surface.

information, and on the basis of geologic and other factors, several areas of the county were targeted for site-specific evaluation as potential landfill sites.

At the Local Level: Siting the Superconducting Super Collider in Northeastern Illinois

A site-specific analysis requires data sets that have the amount of detail or resolution necessary to adequately describe the site. Maps of the United States, the state of Illinois, or a city are different in terms of the type and amount of information they communicate. Site-specific analysis requires data at an appropriate scale capable of identifying or expressing the physical character of the landscape and its human-imposed structures and boundaries.

This example concerns the Illinois bid for the proposed location of the U.S. Department of Energy's Superconducting Super Collider (SSC). Illinois was selected as a finalist in the national competition for siting this high-energy physics facility designed to be the most powerful particle accelerator in the world. The GIS was used as a siting tool throughout the 5-year SSC competition. Among the many automated maps used as part of the siting effort were soils, bedrock geology, seismic risk areas, flood hazard areas, threatened and endangered species habitats, known paleontological sites, archaeological site probability, Illinois historic landmarks, population density, highways and railroads, and water wells. The ability of the system to synthesize these numerous data layers allowed decision makers to explore the effects of various siting alternatives.

Initially, the GIS was used by decision makers to help identify the best possible site for the entire 53-mile, oval-shaped SSC tunnel and its associated surface facilities. Finding a site that would have minimal negative impact on surface lands and homeowners in the area and no fatal flaws was a challenging task. The GIS was instrumental in meeting this challenge. After a site was identified that satisfied the project specifications, the GIS continued to be used extensively to analyze and assess the potential environmental impacts associated with construction of specific components and operation of the SSC. Much of the information generated from the GIS was provided to the U.S. Department of Energy to assist in its preparation of an environmental impact statement for the project.

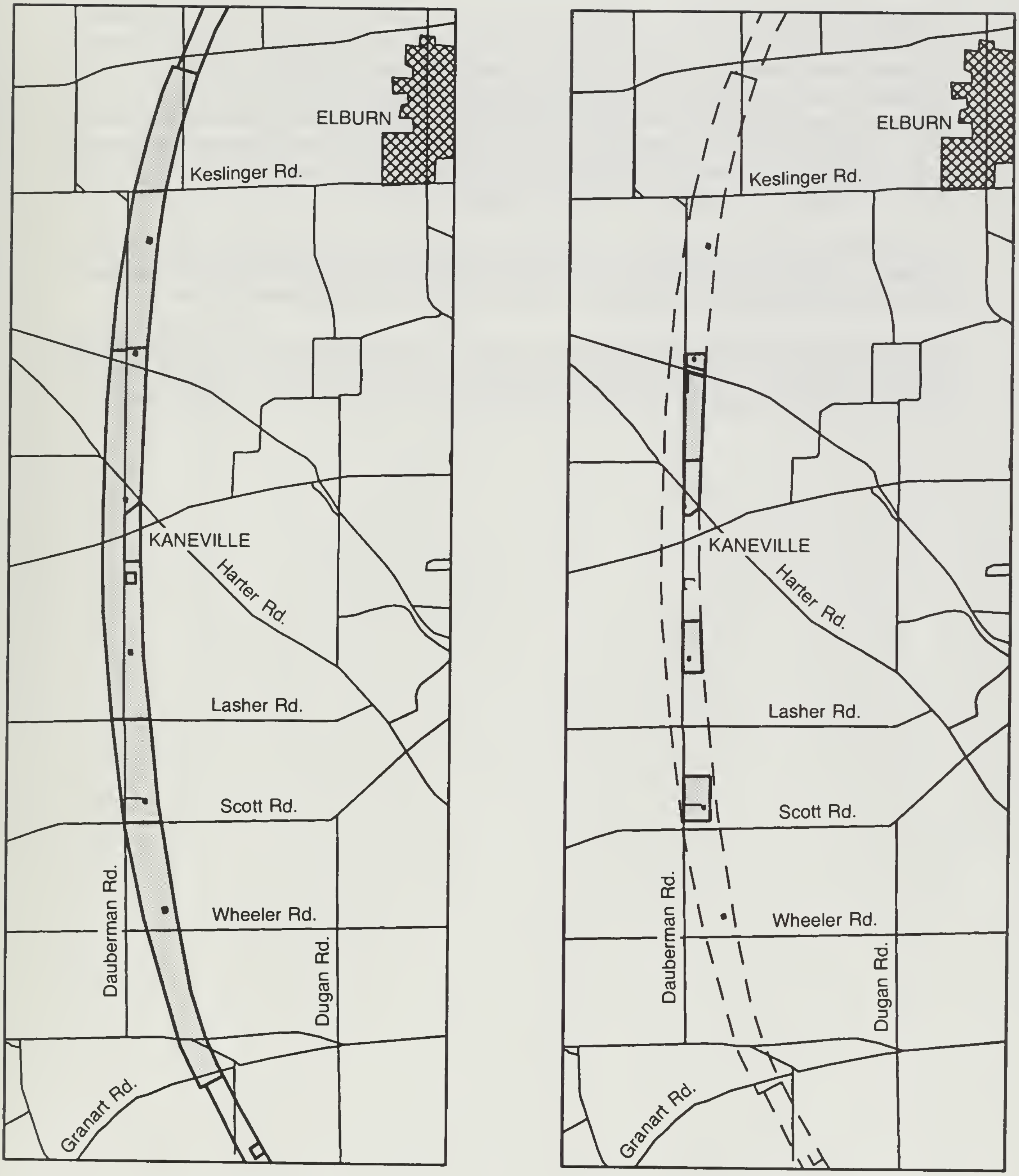
The IGIS was also used for site-specific (local) analysis to explore and compare ways in which the potential impact on land and area residents could be minimized. For example, the proposed configuration of the SSC included two campus areas along the western section requiring large amounts of surface land for office and laboratory buildings, maintenance structures, and access shafts. The initial alignment proposed for the SSC would have affected residents of Kaneville, a rural community in western Kane County, and required a significant number of them to relocate.

To minimize the potential impact to the residents and farming activities, a series of alternatives was developed, of which two are depicted in figure 13. The number of residents affected by each scenario, as well as the acreage of wetlands and total affected acreage, was determined by the GIS. For this part of the SSC study, very detailed data layers were compiled and used, including land parcels that show individual lots and ownership information (1:9,600), wetlands areas as small as one-quarter acre (1:24,000), soil maps used to identify prime farmland (1:15,840), road networks, and others.

Figure 13 (left) shows the original SSC west campus design. In this design, the west campus was to be a contiguous area requiring all shaded land shown. Once the campus area was delineated, it was then overlain on the parcel maps, allowing the number of affected parcels, land uses, and residents to be determined. In addition, GIS was used to calculate the total acreage within the campus area. Under this design scenario, 1,965 acres would have been acquired, 136 parcels affected, and 83 residents relocated.

Figure 13 (right) shows an alternative west campus design. Instead of acquisition of a continuing campus area, this design called for the campus to be broken into three parts. Again, once the new campus outlines were selected, they were overlain on the parcel maps to determine the number of residents affected. Under this design scenario, 272.5 acres would have been acquired, 8 parcels affected, and 1 resident relocated.

These were only two of the numerous west campus designs that were considered. For each design, the number of residents affected and total acreage to be acquired could be determined in a similar way, allowing the number of residents affected to be minimized.



CONTIGUOUS CAMPUS
acreage affected 1965
parcels affected 136
relocations 83

¼ mile

DISCONTIGUOUS CAMPUS
acreage affected 272
parcels affected 8
relocations 1

Figure 13 Options for siting the west campus of the Superconducting Super Collider. Shaded areas represent surface land to be acquired for the project.

The design alternatives were also used to minimize the wetlands acreage to be affected by construction of the SSC west campus. The abundant and diverse wetlands scattered throughout northeastern Illinois are an important resource for flood storage, wildlife habitat, and recreation. One of the goals of the SSC siting study was to minimize the impacts on these important features. In the first alternative, the contiguous campus design, the campus outline was overlain on the wetlands maps to determine the affected wetlands acreage. Under this design scenario, 19 acres of wetlands would have been impacted, and under the second design scenario, the discontiguous campus design, 0.9 acres.

Using these analytical GIS functions, researchers were able to rapidly calculate the number of residents and acreage affected by the numerous design alternatives. These alternatives and their associated tradeoffs could then be compared and evaluated by decision makers.

The SSC siting study further demonstrates the ability of the GIS to be used effectively not only for projects at a statewide or regional level, but also for the analysis and compilation of many diverse, detailed data sets into maps and tables that can be used for site-specific studies.

SUMMARY

The IGIS has become an integral part of ENR, and as the database continues to be updated and expanded in response to the increasing number of projects, its value as a resource will continue to grow. The IGIS has already proven its abilities as a tool for natural resource and socioeconomic planning for the citizens of Illinois and has great potential to expand in this direction. ENR is committed to remaining at the forefront of GIS technology to fulfill the system's promise as a research tool that will benefit Illinois.

FURTHER INFORMATION — ENR AGENCIES

Office of Research and Planning
325 West Adams Street
Springfield, Illinois 62704
Economic development, census data, electronic "Yellow Pages" information
Contact: Timothy Johnson

Illinois State Geological Survey
615 East Peabody Drive
Champaign, Illinois 61820
Mineral resources, groundwater, geologic mapping, ILLIMAP base map system
Contact: E. Donald McKay

Illinois State Water Survey
2204 Griffith Drive
Champaign, Illinois 61820
Surface water resources, climate data
Contact: Michael Terstriep

Illinois Natural History Survey
607 East Peabody Drive
Champaign, Illinois 61820
Wetlands data, natural areas, threatened and endangered species, statewide DLG coverage
Contact: Warren Brigham

Illinois State Museum
1920 10 1/2 Street
Springfield, Illinois 62703
Archaeological and cultural resources
Contact: Michael Wiant

Hazardous Waste Research and Information Center
One East Hazelwood Drive
Champaign, Illinois 61820
Information on hazardous waste sites, hazardous waste generators, and landfills
Contact: Gary Miller

REFERENCES

Dangermond, J., 1976, Integrated terrain unit mapping (ITUM)—an approach for automation of polygon natural resource information: Paper presented at the 1976 Urban and Regional Information Systems Association annual conference, Atlanta, Georgia (paper available from ESRI, Redlands, California).

Dueker, K. J., and D. Kjerne, 1989, Multipurpose cadastre: terms and definitions: Technical Papers, 1989 ACSM-ASPRS Annual Convention, Baltimore, Maryland, 2–7 April 1989, v. 5, p. 94–103.

Environmental Systems Research Institute, 1987, ARC/INFO Users Guide, Volume 1: ESRI, Redlands, California.

Greene, A. V., 1990, Illinois Geographic Information System Index to Automated Statewide Databases: Circular 175, Illinois State Water Survey, Champaign, Illinois.

Intergovernmental Solid Waste Disposal Association, 1990, Landfill facility site identification study: Intergovernmental Solid Waste Disposal Association, Champaign, Illinois.

Treworgy, C. G., C. A. Hindman, L. Pan, and J. W. Baxter, 1989, Evaluation of the potential for damage from subsidence of underground mines in Illinois: Final report to the Illinois Mine Subsidence Insurance Fund, Contract Report 1-5-37891, Illinois State Geological Survey, Champaign, Illinois.

White, M., 1980, A survey of mathematics of maps, p. 82–96: *in* Auto-Carto 4, Proceedings of the International Symposium on Cartography and Computing: Applications in Health and Environment, v. 1, R. T. Aageenbrug, editor, American Congress on Surveying and Mapping and the American Society for Photogrammetry, Falls Church, Virginia.